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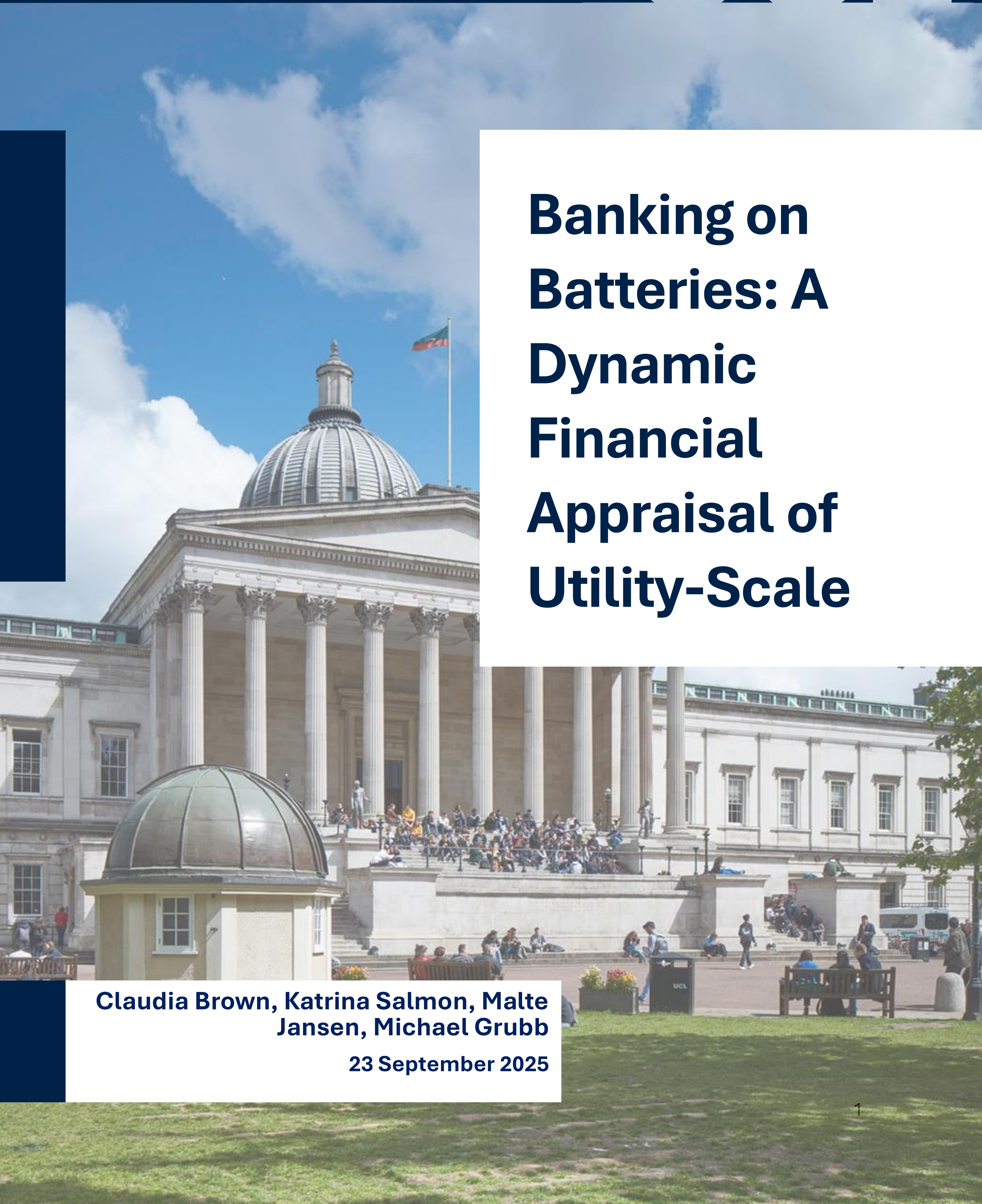

Banking on Batteries: A Dynamic Financial Appraisal of Utility-Scale

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About this publication

This report is released as the third and final publication in a series on the appraisal of battery energy storage systems (BESS) by UCL ISR's Centre for Net Zero Market Design, for the European Investment Bank. The authors take full responsibility for the contents of this report. The opinions expressed do not necessarily reflect the view of the European Investment Bank.

For more information on the series and to read the two prior reports, please visit our website.

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Executive summary

This report for the European Investment Bank (EIB) examines key components of the financial appraisal of utility-scale Battery Energy Storage Systems (BESS) in Europe. It complements our first report for the EIB on the public economic value and appraisal of BESS, and the rationale for organisations such as the EIB to accelerate their investment in BESS. Faster deployment of the technology would provide the flexibility required by increasingly renewable-based energy systems, essential should the EU wish to meet its 2030 decarbonisation targets. While the economic case may be clear, understanding the financial viability of individual BESS projects remains complex.

The challenge

The capital costs of BESS are largely upfront and relatively predictable however its revenues are not. BESS projects rely on stacking and optimising between multiple revenue streams. The streams differ across European countries, with many uncertainties related to potential market saturation, regulatory changes, and evolving electricity system and market dynamics over the 10–15-year lifespan of an asset, during which European power systems are expected to undergo transformative change.

Combining the analysis of past and emerging market trends with a forward-looking qualitative methodology (participatory system mapping), indicators of either more profitable markets or those characterised by lower risk, are identified, as are the key factors likely to influence revenue dynamics over the coming years. This approach complements traditional model-based revenue forecasting by capturing a broad set of interdependencies and uncertainties likely to affect BESS profitability over time.

Three categories of revenue streams

European utility-scale BESS projects typically derive revenues from three core streams: ancillary services, energy arbitrage, and capacity markets. Each stream presents distinct opportunities and risks.

Ancillary Services: These include frequency response and balancing services procured by Transmission System Operators (TSOs). The design of and regulation applied to these markets may differ, and not all TSOs reward BESS for these services. Historically, ancillary services have been the most valuable stream for BESS, accounting for up to 67% of revenues in Europe. However, these markets, particularly the frequency response, are shallow and prone to rapid saturation. For example, following large-scale BESS participation in frequency response (FR) actions, FR revenues in Great Britain dropped by over 80% in two years, with only modest deployment of BESS compared with the amounts required over coming years. The harmonisation of the ancillary service markets across Europe is ongoing, and may improve liquidity, transparency, and promote more efficient resource allocation, but is also likely to reduce prices. We conclude that whilst ancillary services may offer high returns initially, they are unlikely to remain a dominant revenue source. However, 'ancillary services' cover a wide range of functions, and few if any systems reward the full range, the need for which is likely to grow as energy systems decarbonize, so a greater range of ancillary service markets may yet become available to BESS assets.

Energy Arbitrage: Revenue from buying electricity when it is cheap and selling later at higher prices ('arbitrage', within and between wholesale and balancing markets) rose from 9% to 23% of European BESS revenues between 2020 and 2024. Markets with high renewable penetration combined with significant fossil fuel-based peaking generation and little installed PSH and nuclear (e.g., Germany, Netherlands) exhibit the largest price spreads, making arbitrage attractive. European arbitrage revenues are expected to keep growing due to low and negative prices driven by accelerating renewables deployment. However, the longevity of arbitrage revenues will be highly sensitive to factors such as future fossil fuel prices, the degree of renewables overbuild, and the deployment of competing flexibility assets. Price curves may also flatten as BESS deployment increases, which could eventually erode margins. Nonetheless, arbitrage is still expected to become the dominant revenue stream, especially as the ancillary services saturate.

Capacity Markets: Only available in six European countries, but under consideration in eight further, capacity markets auction long-term contracts remunerating assets for their availability, particularly during periods of peak demand. Where available, they provide an important source of revenue stability. While thermal assets were historically the primary recipients of capacity market contracts, in recent years, BESS has gained traction, as may be demonstrated by the results of recent auctions in Poland and Italy. However, shorter-duration BESS assets tend to be subject to relatively severe derating factors, reducing their effective remuneration. Competition faced by BESS from fossil fuel-based generators should continue to decrease as EU decarbonisation objectives support low carbon alternatives. On the other hand, the de-rating of particularly shorter duration BESS assets may become increasingly severe as the variability of the generation stack increases and the potential duration of periods of system stress become longer. While valuable for de-risking investments, capacity markets but may contribute a smaller share of total revenues over time.

Project-level evaluation: indicators of improved financial performance and reduced revenue vulnerability for prospective BESS projects

1) **Access to all revenue streams:** BESS in jurisdictions permitting access to the ancillary services, energy arbitrage, and capacity markets, that allow revenues to be stacked across the streams, increases the likelihood of a more resilient business case. Optimisers may then be employed to find the most lucrative routes to market.
2) **Regulatory environments with digitalised system operations:** Regions with digitalised grid operations and low skip rates (i.e. where BESS is not routinely bypassed in dispatch decisions) offer more reliable revenue capture.
3) **Markets with high and volatile price spreads:** These are typically characterised by high renewable penetration (especially solar), continued reliance on fossil fuels as the marginal generator for a significant portion of hours, and limited low-cost dispatchable capacity. Such conditions enhance arbitrage opportunities.
4) **Revenue stability through capacity mechanisms:** Where available, capacity markets or other innovative schemes like Italy's MACSE (see page 69) can provide long-term contracts that reduce revenue volatility and improve bankability.
5) **Optimised asset characteristics:** Short-duration BESS may initially perform well in frequency response markets, but longer-duration assets are better suited for arbitrage and capacity markets. The EIB should also consider financing augmentation projects (where the duration of an existing site is increased, as opposed to installing the same cells as a new asset elsewhere), which will likely facilitate higher arbitrage revenues once the ancillary services saturate.
6) **Locational factors:** Grid congestion and regional fee structures can significantly affect profitability. Projects near congestion points may benefit from congestion management revenues, but these are vulnerable to cannibalisation and future network upgrades. Monitor locational pricing reforms and grid fee structures closely.

Methodological recommendations: towards a dynamic financial appraisal framework

Given the evolving nature of electricity markets and the complexity of BESS revenue streams, the EIB should adopt a **dynamic, systems-based approach** to financial appraisal. Key methodological recommendations include:

1) **Move beyond static back-testing**: Historical revenue performance is not a reliable indicator of future viability. Revenue streams, especially the ancillary services, can saturate rapidly, and market conditions can shift within a single year.

2) **Integrate qualitative insights from participatory system mapping**: This method identifies key variables likely to impact BESS revenues over time. An understanding of

the uncertainties, interactions and non-linear dynamics captured by this method may be used to complement more traditional quantitative modelling.

3) **Monitor key variables over time**: Key variables impacting BESS revenues across the core streams include but are not limited to fossil fuel prices, renewables deployment and investment in the network. Tracking the full set of variables using published energy scenarios allows for more informed assessments of revenue potential.

4) **Use system maps to inform and validate modelling assumptions**: When projecting revenues, ensure that forecasting models reflect the structural changes expected in electricity markets, as well as realistic assumptions about market evolution and policy changes. System maps can help identify which variables should be included as inputs and how their evolution might affect outputs.

5) **Tailor system mapping to regional contexts**: Use country-specific energy scenarios to assess how local market dynamics may impact BESS revenues. This is particularly important for evaluating projects in regions with emerging or reforming BESS markets.

6) **Update appraisal frameworks regularly**: As new technologies (e.g. long-duration storage), market mechanisms, and regulatory reforms emerge, the EIB's appraisal methodology should evolve accordingly. Consider conducting internal or expert-led system mapping exercises to stay ahead of market developments.

Conclusion

The financial viability of utility-scale BESS projects hinges on a complex interplay of market dynamics, regulatory frameworks, and technological characteristics. While costs are largely upfront and predictable, revenues are uncertain and evolving. To support investment in BESS and accelerate the energy transition, the EIB must adopt a dynamic approach to financial appraisal. By combining typical model-based revenue forecasting with qualitative system mapping and scenario analysis, the EIB can better assess risks and opportunities to make informed investment decisions that align with Europe's decarbonisation goals.

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List of Abbreviations and Acronyms

BESS: battery energy storage systems

BSPs: balancing service providers

BtM: behind the meter

Capex: capital expenditure

CBA: cost benefit analysis

CfD: contracts for difference

DSR: demand side response

EC: European Commission, or ‘the Commission’

EIB: European Investment Bank

EMDR: electricity market design reform

EPC: engineering, procurement and construction

EU: European Union

GB: Great Britain

IRR: internal rate of return

LFP: lithium iron phosphate

NESO: National Energy System Operator (in Great Britain)

NMC: lithium nickel manganese cobalt oxides

Opex: operational expenditure (including ongoing fixed costs)

PSH: pumped storage hydro

RO: renewables obligation

SO: system operator

TSO: transmission system operator

WACC: weighted average cost of capital

Frequency and system stability markets:

FCR: frequency containment reserve

FCR-N: frequency containment reserve for normal operation

FCR-D: frequency containment reserve for disturbances

aFRR: automatic frequency restoration reserve

PICASSO: Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation

mFRR: manual frequency restoration reserve

MARI: Manually Activated Reserves Initiative

RR: restoration reserve

TERRE: Trans-European Replacement Reserves Exchange

Glossary

Cycle life/lifetime: the amount of time or cycles a BESS can provide regular charging and discharging before failure or significant degradation. From (NREL, 2019)

Energy capacity: the maximum amount of stored energy (measured in MWh). From (NREL, 2019)

Rated power capacity: the total possible instantaneous discharge capability (measured in MW) of the BESS, or the maximum rate of discharge that the BESS can achieve, starting from a fully charged state. From (NREL, 2019)

Skip rate: The ‘skip rate’ is frequency with which a non-economic dispatch decision is made, for example dispatching a more expensive thermal asset as opposed to a cheaper BESS asset to balance the system (NESO, 2024)

State of charge: expressed as a percentage, represents the battery’s present level of charge and ranges from completely discharged to fully charged. The state of charge influences a battery’s ability to provide energy or ancillary services to the grid at any given time. From (NREL, 2019)

Storage duration: the amount of time storage can discharge at its power capacity before depleting its energy capacity. For example, a battery with 1 MW of power capacity and 4 MWh of usable energy capacity will have a storage duration of four hours. From (NREL, 2019)

1 Introduction

1.1 European decarbonisation and storage targets

In an important drive to achieve climate neutrality by 2050, the European Union has enshrined in law the interim target of reducing emissions by 55% compared with 1990 levels (European Council, 2025). To reach this milestone, the share of electricity generated by renewable energy sources must reach an estimated 69%, requiring an increase of over 20% within the next 5 years (European Commission, 2023). Member states are thereby progressively replacing fossil fuel-based generation with renewables; in 2024, European fossil fuel generation declined 9% while renewables rose 7.6%, compared with just the year prior.

The replacement of polluting incumbents with clean renewables, characterised by variable generation profiles determined largely by weather patterns, creates the need for increased energy system flexibility. Energy storage is a key asset class capable of providing said flexibility, alongside numerous additional system services such as energy security and network stability which will be required as we reduce our dependence on fossil fuels. Accordingly, the European Commission (2023) estimates the need for more than 200 GW of storage by 2030, rising to 600 GW by 2050.

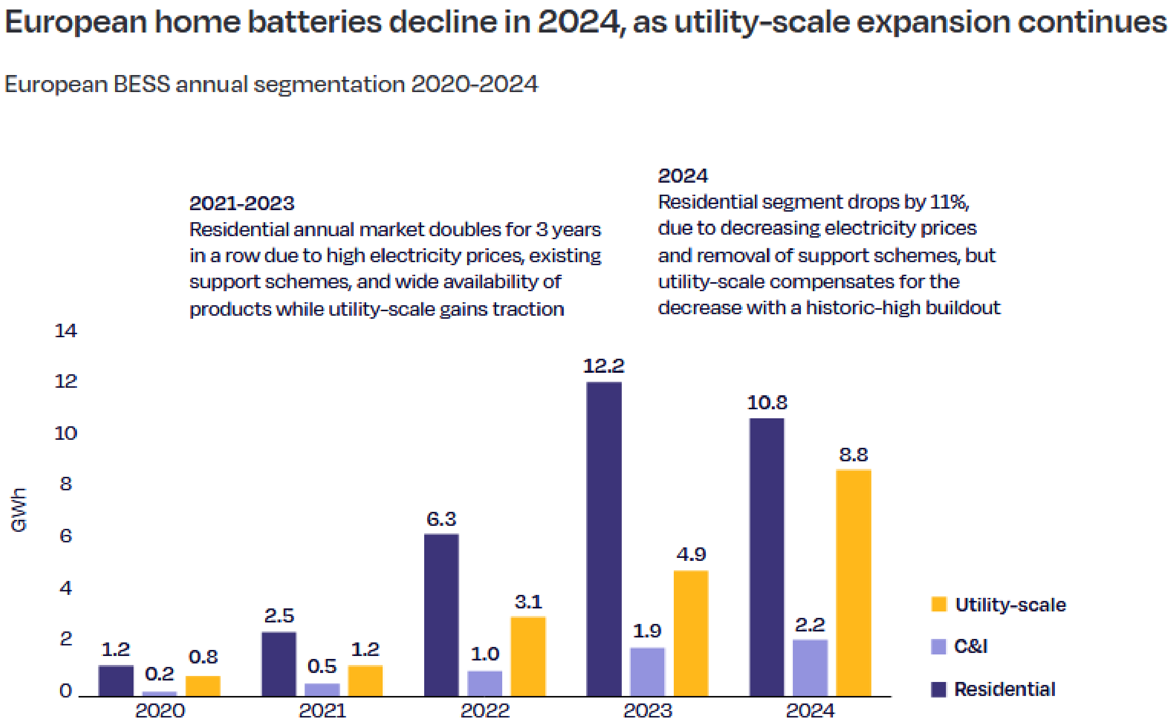
1.2 Types of storage and their current deployment

Currently, there are only around 60 GW of energy storage within the EU, predominantly from pumped-storage hydropower (PSH) (European Commission, 2025). There is scope to further increase PSH capacity in Europe, but with the most viable sites already developed, the scale of its potential expansion is likely to be limited, and or costly (Quaranta *et al.*, 2024). Further, new projects are often subject to lengthy construction timelines. Therefore, whilst PSH has been the dominant source of energy storage thus far, it will not deliver against the Commission’s 2030 target.

Several alternative storage technologies exist at various technology readiness levels, but battery energy storage systems (BESS) have emerged as one of the most promising. BESS has been touted by Solar Power Europe (2025a) as the “absolute short cut to delivering the flexible, electrified energy system that is foundational to EU energy security and competitiveness goals”.

Lithium-ion battery technologies account for the vast majority of global BESS deployment (IEA, 2024a). They are modular in nature, have fast response times, high energy density and relatively low costs but experience high degradation, limiting total cycle-life (Schmidt and Staffell, 2023). The typical discharge duration of BESS has tended to be relatively short, with the average duration of operational assets across Europe averaging between 0 and 1 hours. However, their durations are gradually increasing, with assets of 1-to-2-hour durations accounting for the greatest share of new projects over the last few years (EASE and LCP Delta, 2024). The trend to increasing duration is clear, with some 4-hour projects expected to come online in Europe in the relatively short term.

Indeed, BESS deployment in Greater Europe has been building momentum, with a compound annual growth rate of 47% between 2018 and 2021, increasing to 58% between 2021 and 2024. By the end of 2024, the European Union had 49.1 GWh of BESS online, while Greater Europe had 61.1 GWh (Solar Power Europe, 2025a).



European home batteries decline in 2024, as utility-scale expansion continues

European BESS annual segmentation 2020-2024

2021-2023
Residential annual market doubles for 3 years in a row due to high electricity prices, existing support schemes, and wide availability of products while utility-scale gains traction

2024
Residential segment drops by 11%, due to decreasing electricity prices and removal of support schemes, but utility-scale compensates for the decrease with a historic-high buildout

Figure 1: The segmentation of European BESS (in GWh) by type (residential, commercial & industrial, and utility-scale) between 2020 and 2024. Source: Solar Power Europe (2025a).

BESS can be installed either commercially or residentially behind-the-meter (BtM), co-located with generation, or as utility-scale stand-alone assets. Residential BESS has been, and continues to be, the most widely deployed in Europe, accounting for 57% of total installed capacity in (GW), compared with only 33% for utility-scale. However, utility-scale demonstrated meaningful growth last year resulting in their market share by capacity increasing by 14%, closing the gap as the growth of residential BESS waned. Solar Power Europe projects that by 2025-end, utility scale will have captured 55% market share, while residential will only account for 33%. In fact, the IEA (2023b) projects that utility-scale BESS will represent the majority of energy storage growth worldwide.

For more information on co-located and BtM BESS, please see our briefing paper to the EIB (Salmon, Jansen and Grubb, 2025).

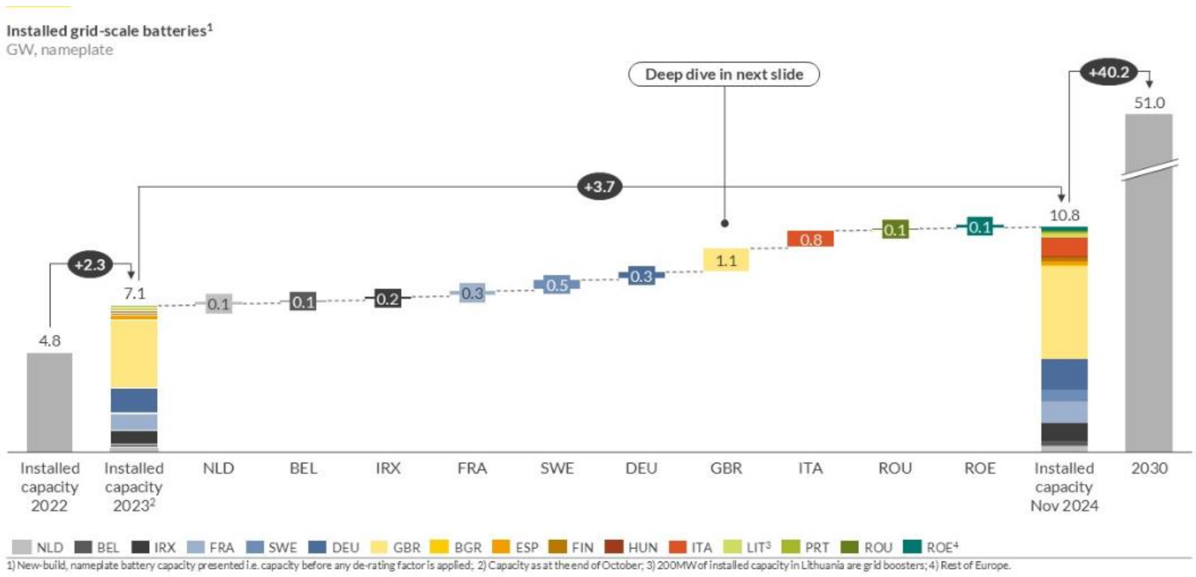


Figure 2: 2024 deployment of grid-scale BESS by European country. Source: Aurora (2025g).

As is detailed in Figure 2, 3.7 GW of utility-scale BESS were brought online during 2024, bringing total installed capacity to 10.8 GW (Aurora, 2025g). Growth was driven by 9 core markets. Great Britain deployed the greatest capacity of 1.1 GW, continuing to pave the way as the leading European market for utility-scale BESS. Not far behind was Italy with 0.8, followed by Sweden with 0.5, Germany and France each with 0.3, and Ireland with 0.2 GW. Belgium, the Netherlands and Romania each added 100 MW.

1.3 The need for accelerated investment in utility-scale BESS

Utility-scale BESS is expected to be play a leading role as a key source of flexibility facilitating power system decarbonisation. But without Great Britain's 4.3 GW, the bloc is left with only 6.5 GW installed, and an increase of only 2.6 GW last year. Should the European Union wish to meet the Commission's legally binding decarbonisation targets, a step change in rate of utility-scale BESS deployment will be required. Actors such as the European Investment Bank (EIB) could be pivotal in boosting investment, thereby accelerating the roll out of this important technology.

In our first report to the European Investment Bank, Salmon and Grubb (2025) outlined the *economic case* for further investment in BESS. They explained the importance of taking a holistic view of the system-level risks and opportunities related to further investment in BESS. This enables proper accounting for the ability of BESS to activate positive feedback loops, often poorly captured in traditional cost benefit analyses (CBA), such as driving technology cost reductions, stimulating further renewables deployment and ultimately achieving system-wide emissions reductions. Corresponding modifications to the EIB's existing methodology for the economic appraisal of BESS were suggested.

1.4 Introducing the financial assessment of utility-scale BESS

While the *economic case* to boost investment in utility-scale BESS projects may be clear, the *financial prospects* for an induvial investment involve multiple uncertainties, many outside the control of the investor. We identify at least three different streams of potential revenue, but whether, or by how much these are remunerated depends on markets and policies that differ by country, and may vary substantially over time.

Complicating this further, BESS provides services that are in effect a hybrid between the roles of demand (when charging) and generation (when discharging), constrained by battery duration. Both costs and revenues vary in complex ways, and even the legal classifications and constraints vary.

In this report to the EIB, we endeavour to provide overarching guidance to inform the financial appraisal of utility-scale BESS projects in Europe. The report begins in Section 2 with a brief overview of cost trends and forecasts given their importance to the overall financial success of a project. The remainder of the report focuses on revenues.

In Section 3, the three core revenue streams often accessible to utility-scale BESS assets across Europe are presented. The current drivers of prices and recent trends across the three streams are then explored. Recognising the importance of taking a dynamic approach to the financial assessment of BESS, Section 3 also looks forward. Key factors that *could* impact revenues across the three streams over the coming years are identified using participatory system mapping, the findings of which are discussed. The implications of both the emerging trends and the key factors identified as integral to the revenue outlook for BESS, are summarised.

In Section 4, three case studies, Spain, Italy and the Netherlands, are presented. Italy has exhibited strong roll out of utility-scale BESS while Spain has struggled to establish a sufficiently attractive market despite the growing need for sources of low carbon flexibility. With an increasingly constrained grid, the Netherlands face specific challenges related to the high fees currently applied to utility-scale BESS. The factors differentiating the three markets are discussed.

Section 5 summarises the findings emerging from this research and concludes with guidance for the EIB including both principles to improve the financial outlook and de-risk the BESS business case, as well as recommendations relating to the methodology used for financial appraisal.

2 An overview of utility-scale BESS costs

2.1 Cost structure

Akin to wind and solar technologies, BESS are capital intensive. They exhibit high up-front costs but minimal day to day expenditure from operating and maintaining the assets. Total capital expenditure (capex) includes numerous components such as the costs of engineering, procurement and construction (EPC), developer margins, the cost of installation, the inverter, grid connection, and the battery cabinets themselves. The ‘Containerised BESS Units’, which aggregate the battery cabinets, inverter and integrating electronics, account for the most significant portion of capex; for a 50 MW, 100MWh utility-scale BESS, Modo Energy (2024c) estimates the units to account for around 75%.

Modo also find that capex broadly increases with the duration of an asset (hours), but that grid connection costs and inverters generally scale with total ‘rated power’ (MW). Therefore, for the same 50 MW system in Great Britain, increasing the duration of the asset from 1 to 2 hours only increases the total capex by about 70%. Using *global* data from 2023, IRENA (2024) determined that increasing the duration of BESS from one to four hours decreased the cost per kWh by approximately 20%.

Methodology used to calculate grid fees can vary significantly between transmission system operators (TSOs) and may also differ depending on the location of the asset within the network. Hence, grid fees must be examined on a case-by-case basis during the financial appraisal of any prospective project. A case study illustrating the potential impact of high grid fees on the overall BESS investment case is presented in Section 4.3.

The average ongoing operational expenditure (opex), mostly fixed, is estimated to be 22% of yearly revenues for an asset in Great Britain, covering costs such as maintenance, land leases, warranties and optimiser fees (Modo Energy, 2024c). After installation, batteries are typically operated by entities known as ‘optimisers’ to manage asset operation; they select the most appropriate route to market across the numerous revenue streams to maximise profits. Optimisers typically negotiate a fee in the region of 5-10% of total revenues, thereby accounting for a meaningful portion of opex.

Given that opex accounts for a comparatively small component of total costs, the remainder of this section will focus on capex.

As a metric for overall costs, the literature tends to focus on cost per unit of storage capacity (kWh), reflecting overall energy capacity (which includes asset duration), rather than cost per kW which would relate to rated power (kW).

2.2 Cost trends and projections

The individual BESS project proposals evaluated by the EIB would likely come with precise cost estimates, and given the up-front nature of BESS costs, these estimates are unlikely to be characterised by particularly high uncertainty. This section therefore gives a more strategic overview of the drivers of cost reductions, both historically and expected future levers, as well as recent developments in battery innovation and issues related to critical minerals.

2.2.1 The drivers of significant cost reductions

Between 2010 and 2023, utility-scale BESS costs declined by 89% globally, from a cost of 2,511$/kWh to 273 $/kWh, as is represented by the line chart of Figure 3. The dramatic reduction in costs has been a key driver of BESS deployment, which has particularly accelerated over the last few years (Figure 3 bars).

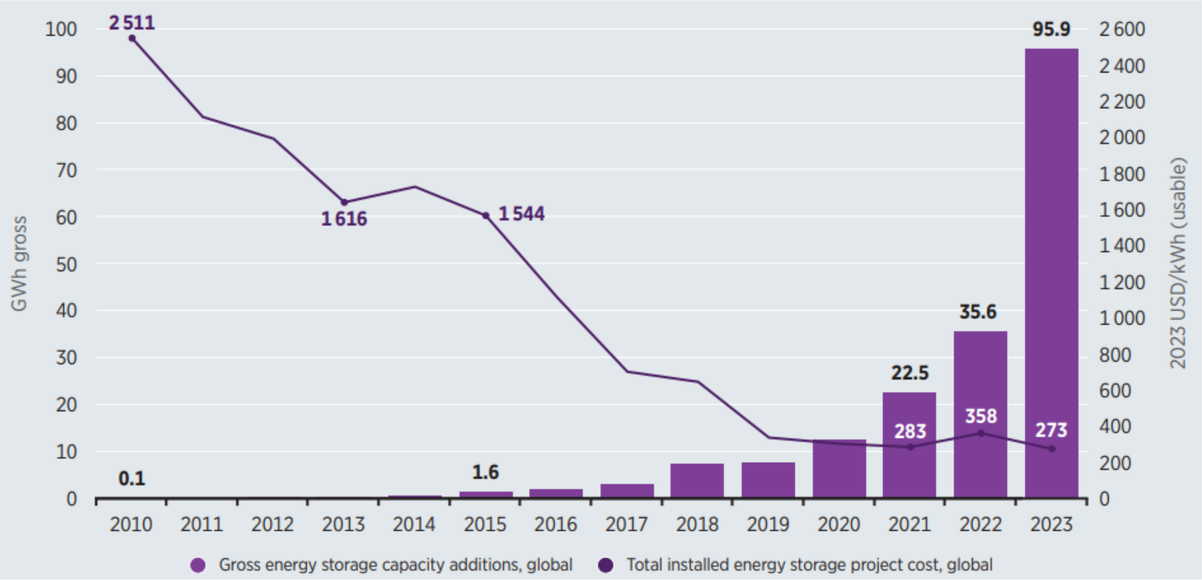


Figure 3: Global gross utility-scale BESS capacity additions per year and total installed project costs between 2010 and 2023. Source: IRENA (2024).

Cost reductions have been driven by numerous factors. Since first commercialisation in the early 1990s, lithium-ion batteries were adopted for a range of applications, including for consumer electronics and electric vehicles (EVs). Progressive cost reductions were achieved by the processes of innovation in lithium-ion technology across the various sectors, with prices eventually dropping low enough to make feasible their application for stationary energy storage systems (Schmidt and Staffell, 2023). Indeed, across all cell types, the real prices of lithium-ion batteries have reduced by over 97% since 1991 (Ziegler and Trancik, 2021).

Within the BESS sector, further cost reductions have been achieved via technological innovation including better manufacturing processes, improved materials efficiency and the expansion of manufacturing capacity which has led to reaching economies of scale (IRENA, 2024). This has included an expansion of upstream mining and material supply chains to support rising demand for lithium ion batteries (Solar Power Europe, 2025a). The rapid growth of BESS markets in recent years has increased competition across the value chain, putting downward pressure on prices. Whilst much of the primary innovation has historically been for other applications, the energy sector now dominates battery capacity deployment, accounting for 90% of annual demand for lithium-ion batteries, up from 50% in just 2016 (IEA, 2024a). Within the energy sector, BESS is the leading market having demonstrated 52% market growth in 2024 compared with 25% for EVs (Rho Motion, 2025).

2.2.2 Ongoing innovation: a change in dominant battery chemistry

Numerous battery chemistries exist under the lithium-ion umbrella. The choice of cathode and anode composition significantly impact performance, safety and cost. There are two leading chemistries:

- Lithium iron phosphate (better known as LFP), and
- Lithium nickel manganese cobalt oxides (NMC).

Both are considered well-balanced across a range of desirable properties, as is illustrated by Schmidt and Staffell (2023) in Figure 4 below.

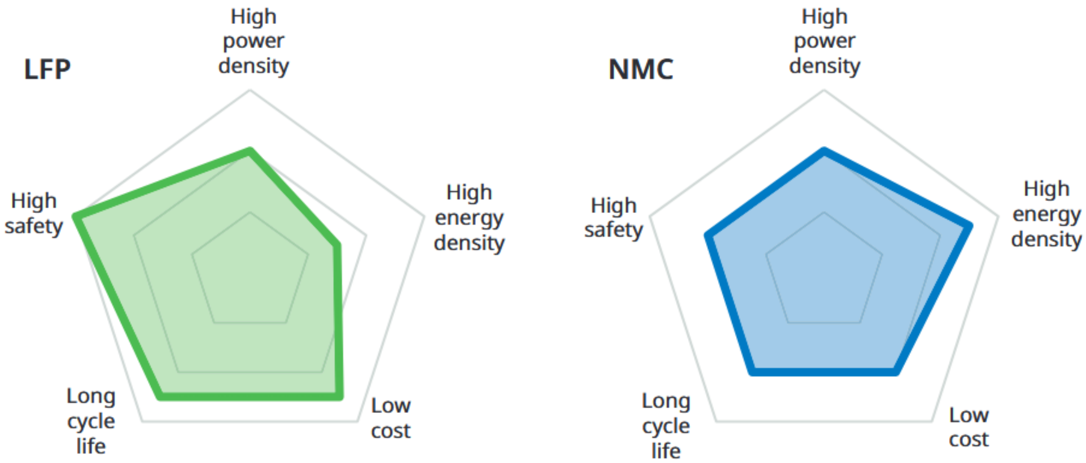


Figure 4: Qualitative assessment of lithium-ion battery properties for LFP and NMC cathode chemistries. Source: Schmidt and Staffell (2023).

Until 2021, NMC was the chemistry of choice, but ‘cell-to-pack’ innovation[1] in LFP cells pioneered by Chinese firm BYD resulted in energy dentistry improvements, meaningfully bringing down costs compared with NMC alternatives (Modo Energy, 2024a). LFP competitiveness improved, leading to significant market growth, aided by additional factors including LFP’s higher cycle-life, improved safety and large Chinese manufacturing capacity. By 2023, LFP cells were 32% cheaper than NMC, and as a result accounted for 84% of annual BESS capacity additions compared with 33% in 2020 (BloombergNEF, 2023, 2024). LFP is now projected to remain the dominant chemistry out to 2030 (IRENA, 2024).

2.2.3 The role of critical minerals: past and future

Technological innovation and cost reductions due to economies of scale mean that the portion of overall battery costs now accounted for by raw materials has increased (Solar Power Europe, 2025a). BESS costs are therefore increasingly sensitive to critical minerals prices, which, as with many internationally traded commodities, are volatile. Figure 3 shows a rise in overall BESS costs in 2022, caused by critical minerals price spikes, as shown in Figure 5. Indeed, between January 2021 and December 2022, lithium prices had increased 9-fold (IEA, 2024a). All components of the lithium value chain surged, and battery production costs rose by 22%. After which, in 2023, not only did supply rapidly recover, but China experienced significant manufacturing overcapacity, leading to record-breaking low BESS prices (Solar Power Europe, 2025a).

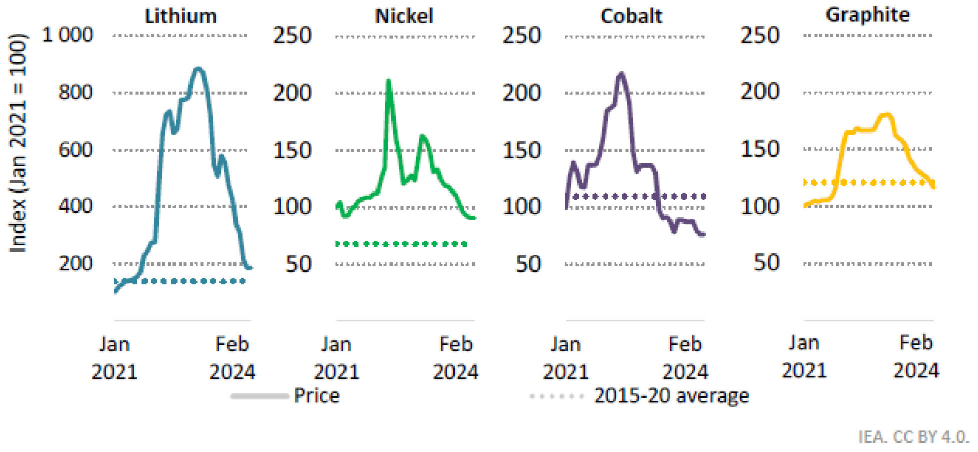


Figure 5: Price developments for key BESS materials between January 2021 and February 2024. Source: IEA (2024a).

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[1] ‘Cell-to-pack innovation’ in LFP cells refers to a fundamental change in structure. Prior to ‘cell-to-pack innovation’, LFP batteries consisted of cells, found within modules, located inside of a pack. Cells are the containers chemically storing electricity, modules mechanically group the cells into units, which are then aggregated in the packs capable of delivering power (Automotive Cells Company, 2022). BYD’s innovation allowed LFP batteries to deliver power without the need for the intermediate ‘module’ layer.

Given the projected role of critical minerals, particularly lithium, in the electrification of numerous end-use sectors globally, levels of demand are only set to rise. Whilst estimates suggest the global resources of key materials will be more than sufficient (Energy Transitions Commission, 2023), it is clear that future BESS cost reductions will be dependent on the ability of supply chains to scale sufficiently rapidly with future levels of demand. Reducing the reliance of utility-scale BESS on critical minerals via further battery chemistry innovation, improvements to energy density, battery lifecycles and recycling processes will also help to decouple the cost of BESS assets with critical minerals (Solar Power Europe, 2025a). Other technologies less reliant on critical raw materials, such as sodium ion and flow batteries, may also help to relieve pressures on supply and ultimately prices (EASE and LCP Delta, 2024; Hughes, 2025).

2.2.4 Future costs and implications

Aside from potential upwards pressure on prices due to bottlenecks in critical minerals supply chains, projections widely show that BESS costs should decline further. Already, 2024 saw a 40% reduction in average costs compared with the year prior, bringing the total cost of a ‘turnkey energy storage system’ to 165$/kWh (Energy Storage News, 2025a). EY (2024) projects cost reductions by a further 20-30% across key markets by 2030. Said cost reductions are expected to come from innovation at the cell level, including improvements to materials efficiency and energy density, increasing the capacity of cells. Resultantly, with a higher proportion of total costs accounted for by individual cells, Modo Energy (2024e) project that future capex reductions will be the steepest for batteries of longer duration. Solar Power Europe (2025a) also predict that increasingly automated factories in China will help to drive down BESS production costs.

Thus far, cost reductions have encouraged the deployment of utility-scale BESS to accelerate. As will be discussed in Section ⍰, an uptick in BESS deployment can expediate the rate at which previously lucrative, but inherently shallow markets saturate. On the other hand, declining cell costs will also reduce the inevitable costs of repowering (the replacement of cells to maintain nameplate capacity due to degradation) and make the augmentation of existing sites (increasing the duration of a BESS project) more profitable. Both repowering and augmentation fall outside of the scope of this report as they would be considered a separate investment requiring financial appraisal, but the potential benefits of augmentation are revisited in Box 2: Optimising BESS duration for arbitrage revenues. under Section 3.4 on the energy arbitrage revenue stream.

3 The revenue streams of utility-scale BESS: from past trends to future considerations

3.1 Markets remunerating the system services provided by BESS

Numerous ‘system services’ are required to maintain stable networks to deliver electricity to consumers across member states. BESS can provide many of these important system services. This section (3.1) briefly outlines the variety of services that BESS can provide, and how the demand for said services will change as energy systems decarbonise and low carbon sources displace incumbents. The remainder of section 3 focuses on the services that have been the most lucrative for BESS thus far, and the markets that remunerate them.

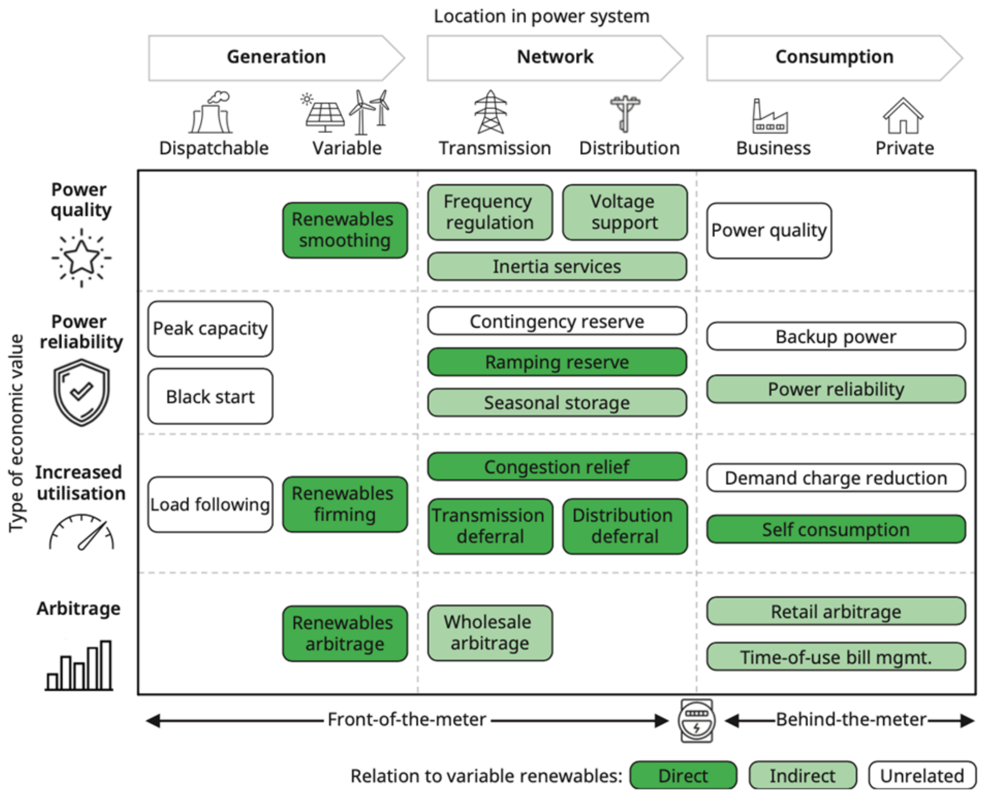

Figure 6: System services that BESS can provide, categorised in relation to the rise of variable renewables. Source: Schmidt and Staffell (2023).

As synchronous generation sources, traditional thermal assets have provided several of these essential system services somewhat passively, including the provision of inertia and short circuit levels (Carbon Trust, 2023). As thermal incumbents are gradually replaced by asynchronous renewables, many of these services will need to be procured elsewhere. Indeed, numerous services will simply require a one-for-one replacement, such as ‘black start’, with no increase in the capacity required. Some services will see an increase in demand as more renewables come online, including frequency regulation, inertia services, and wholesale arbitrage. Finally, the rise of renewables will also necessitate numerous new services, for example congestion relief, helping to minimise costly network upgrades. Schmidt and Staffell (2023) represent these three categories of service in Figure 6 (above): clear boxes represent services unrelated to the rise of renewables, light green boxes represent the services that will see an increase in demand, the dark green represent entirely new services.

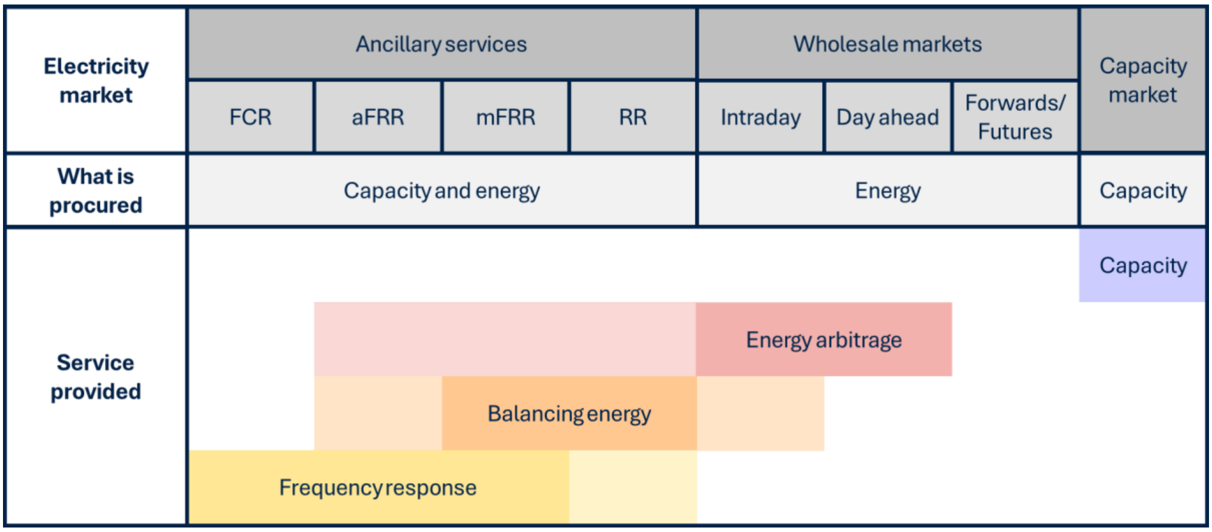

Figure 7: Schematic illustrating the core markets across which BESS may accrue revenue for services provided to the system. Source: Author.

Four core categories of system service are, at present, the most lucrative for BESS in Europe and thereby important for their financial appraisal: frequency response, balancing energy, energy arbitrage, and capacity. These four services are remunerated across numerous electricity markets, as is illustrated in Figure 7, but may be categorised under three widely recognised revenue streams: ancillary services, energy arbitrage, and capacity markets. Depending on regulation in individual member states, BESS can optimise their operation to provide energy and capacity for numerous system services to accrue maximum revenues across the core streams, whilst observing the contractual obligations from each stream. This is known as revenue stacking.

The remainder of this section examines each revenue stream in some detail; the Ancillary Services in Section 3.3, Energy Arbitrage in Section 3.4 and Capacity Markets in Section 3.5. For each revenue stream, past and emerging trends that are important consider in the financial assessment of a BESS project are presented. But as is exemplified by the recent saturation of frequency response markets in some European contexts (detailed on page 30), BESS revenues may change significantly in a short space of time. The design of electricity markets and policies are also rapidly evolving. A dynamic view of each revenue stream is, therefore, essential for a robust financial appraisal of a prospective project.

3.2 Analytic approaches to evaluating future revenues: introducing participatory system mapping

To complement analysis of *past and current* trends, a participatory system mapping approach is applied to investigate the *outlook* for BESS revenues.

Participatory system mapping is a qualitative method that leverages the knowledge of experts to create a network of factors and their causal connections (Barbrook-Johnson and Penn, 2022). In this case, the 'factors' connected in a network are variables that may impact the future of revenues accrued by BESS. Two workshops were conducted, with a range of electricity market and storage experts in attendance, to produce four system maps; one map for each of the four system services for which BESS is mostly widely remunerated. Thereby, across the core revenue streams, a full range of specific factors upon which experts believe future BESS revenues will hinge, are identified. The maps also capture the nature of interactions between key factors, including whether the factors are connected by positive or negative interactions, i.e. whether an increase or decrease in one factor (variable) will ultimately increase or decrease BESS revenues. The maps also capture where experts believed interactions may be weaker, conditional, or uncertain.[2]

The system maps may be used by the EIB in conjunction with country-specific energy system scenarios, published either at the member state or EU level. Scenarios facilitate an understanding of whether and/or how the variables identified in these maps are likely to change, and on what time horizon. In the context of conducting a financial appraisal for a BESS project, tracking how the factors identified in the system maps may change throughout energy system transition would allow the EIB to evaluate the potential qualitative impact of said changes on BESS revenues throughout the asset's lifetime.

Of course, modelling approaches are typically used to forecast future electricity market prices, and to quantify projected BESS revenues for a prospective project. Whilst models may be useful, necessary simplifications in their representation of reality render their results inherently incorrect (Box and Draper, 1987; Barbrook-Johnson and Penn, 2022). The choice of assumptions and simplifications impact how far from reality the price and revenue projections end up.

For example, the modelling of arbitrage revenues could assume that the deployment of storage, including BESS assets, slows *before* severe flattening of wholesale market price spreads, hence avoiding cannibalisation of the revenue stream. In reality, the extent to which investment decisions are sufficiently responsive to such longer-term risks is uncertain. In Great Britain (GB), we have already seen investment in BESS continue despite high cannibalisation risks in what was previously the most lucrative market.

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[2] Within the system maps, dotted arrows are used to denote said weaker, conditional or uncertain interactions. The nuance is then explained in the discussion of key findings emerging from the maps (found directly after each of the maps).

Continued BESS deployment drove the collapse of frequency response prices, reducing net BESS revenues by over two thirds in a single year (Modo Energy, 2024d), explored further in Section 3.3.5. The EIB should therefore critically evaluate any modelled revenue projections by applying an understanding of the key variables and dynamics captured in the system maps presented in this report. Should the EIB conduct in-house modelling of revenues, the system maps may also serve as valuable input to models.

Presented in sections 3.3.6, 3.4.5 and 3.5.5, the system maps offer a dynamic view of revenues, following the corresponding analysis of past and emerging trends. The key findings from the system maps are discussed. For a full description of the participatory system mapping process, and an explanation of how to read system maps, see Annex 2: The participatory system mapping approach.

3.3 Ancillary services, remunerating frequency response and balancing energy

3.3.1 What are the ancillary services?

Ancillary Services keep the system stable given unanticipated fluctuations in supply and demand. Historically, they were predominantly provided by inertia, intrinsic to large thermal power generation and pumped hydro. Increasingly, TSOs have developed Ancillary Service *markets,* in which both capacity and energy are procured by TSOs to respond to fluctuations in electricity system balance, known as ‘imbalances’.

Imbalances may be caused by a host of factors, including unexpected changes to weather impacting renewables output, disruptions to power plants and sudden shifts in electricity consumption (Comcam, 2024). Whilst individual TSOs may establish their own independent markets to procure unique products to resolve imbalances, the four outlined below are the most common, and are typically dispatched according to the following activation schedule in Figure 8, by (gridX, 2024).

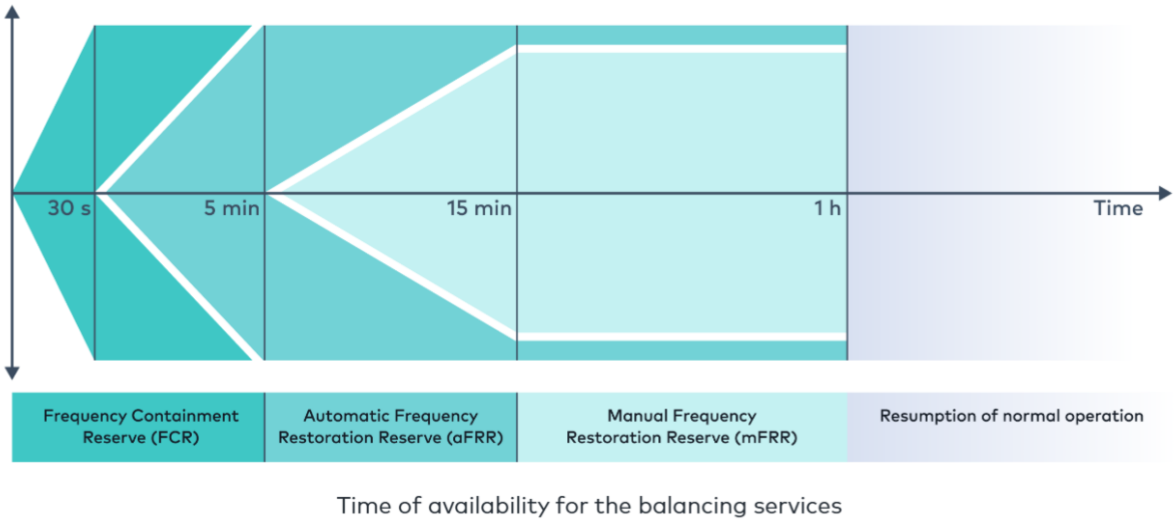

Figure 8: Key European ancillary services, their response times, and the schedule of their activation. Source: gridX (2024). These represent the response timelines for continental Europe. Other timelines may apply in other synchronous areas.

Frequency containment reserve

The frequency containment reserve (FCR) is the primary frequency control, for which capacity and energy are procured to stabilise the system frequency at a stationary value following a disturbance, otherwise referred to as a 'frequency event'. Assets participating in the FCR market are required to provide rapid injections of power to the market, acting for several seconds up to around 15 minutes.

Automatic frequency restoration reserve

Once the frequency of the system has been stabilised to a stationary value, the secondary frequency control, known as the automatic frequency restoration reserve (aFRR) is activated. The aFRR market uses participating assets to bring the frequency back to is target value by automatically adjusting their active power levels. The assets may be required to provide power for anywhere from 30 seconds up to around a quarter of an hour. aFRR markets may also be used to resolve larger imbalances in supply and demand, and whilst rare, in some regions manage network congestion.

Manual frequency restoration reserve

The manual frequency restoration reserve (mFRR) is the tertiary frequency control – the active power reserves used to respond to longer lasting frequency deviations that the primary and secondary reserves cannot resolve alone (Artelys, 2022). mFRR thereby includes the energy required to correct larger imbalances in supply and demand, for example caused by deviations to wholesale market schedules. In this report, we refer to this service as 'balancing', distinct from 'frequency response', with the former requiring greater capacity than the latter. Included within 'balancing' is also the capacity required to manage network constraints, also predominantly procured within mFRR markets. Assets participating in mFRR are manually activated by TSOs, and are required to respond across a time horizon from five minutes up to hours.

Restoration reserve

Restoration reserves (RR) are the final active power reserves, procured to support the replenishment of the frequency restoration reserves to prepare for further imbalances of the system.[3]

The distinction between 'frequency response' and 'balancing energy'

The activation schedule described above illustrates the overlapping procurement of 'frequency response' and 'balancing energy' across the ancillary service markets in Europe. Whilst in practise there is no clear distinction, this report differentiates the two system services:

- ***Frequency response.*** Frequency response services stabilise and adjust system frequency to respond to disruptions. While disruptions to system frequency may often originate from imbalances in supply and demand, they are not the only cause. We consider the majority of frequency response capacity and energy to be procured in the FCR, aFRR and mFRR markets.
- ***Balancing energy.*** Larger imbalances in supply and demand generally require greater volumes of energy to be traded than are needed solely to stabilise frequency. In addition to the energy required to manage network constraints, we consider the capacity and energy to resolve these larger imbalanced to be 'balancing energy'. Most balancing capacity and energy are procured in the mFRR and RR markets. Some balancing energy may also be procured in the aFRR market, particularly in Sweden, Switzerland, Hungary, and Bosnia and Herzegovina where energy for congestion management may be also procured in the aFRR markets (ENTSOE, 2023).

Generally speaking, BESS of much smaller total capacity and shorter duration, but able to rapidly inject power to the grid, are sufficient to provide frequency response services, whereas BESS of slightly larger energy capacity and of longer duration may be required to provide 'balancing energy', including congestion management.

In Great Britain there is a distinct 'balancing mechanism', which entirely separates the procurement of balancing energy from frequency response or other ancillary services. But even amongst European TSOs, the approach to balancing energy procurement can

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[3] Not to be confused with black start.

differ. German TSOs take a more reactive approach, relying more so on their liquid intraday markets to resolve last minute imbalances in supply and demand. Other European TSOs with less liquid intraday markets take a more proactive approach, securing the majority of balancing capacity using their ancillary service markets and designated balancing products (Bah, 2024). The window between gate closure and energy dispatch in the intraday markets impacts the ratio of balancing energy procured in the ancillary service markets versus the intraday; the smaller the window, the more capable the intraday markets are at resolving last minute imbalances, albeit relying on more volatile intraday prices to send sharp operational signals.

Despite blurred lines in their procurement in European markets, the diverging characteristics of ‘frequency response’ and ‘balancing energy’ call for this differentiation to be made.

3.3.2 The heterogeneity of European ancillary services

The ancillary service markets presented above use terminology for the standardised products procured on pan-European platforms, consolidated in response to European Commission (EC) Electricity Balancing (EB) Regulation, established in 2017 to harmonise European electricity markets. We are in the early stages of market harmonisation, therefore at present, the procurement of ancillary services across Europe remains relatively heterogeneous.

TSOs may independently set the rules and regulations for the procurement of capacity and energy across their specific ancillary service products. In their survey, ENTSOE (2023) details a full range of variables regulation at the member state level.[4] Examples of variables include:

1) ***Procurement mechanism.*** TSOs may establish mandates on generating assets to reserve capacity for the provision of ancillary services. Alternatively, they may operate competitive markets.
2) ***Pricing methodology.*** Regulated, ‘pay as bid’ or ‘pay as clear’ pricing mechanisms may be used.
3) ***Asset eligibility.*** TSOs may place restrictions on the asset type and characteristics eligible to access the ancillary service markets. Eligible assets are referred to as ‘Balancing Service Providers’ (BSPs).
    - Assets are categorised as follows: generator, demand side response (DSR), pumped storage, batteries and distributed generation. In Spain, for example,

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[4] ENTSOE (2022) present the comprehensive dataset used to create the survey report, titled ‘Ancillary services survey, Results Excel 2022’, which details member state specifics. ENTSOE are yet to publish an updated survey.

generators are mandated to provide FCR, meaning there are no competitive markets in which BESS can participate to accrue revenue.

  - The distance to real time for the procurement of capacity products may vary from years to days ahead of delivery. Energy products tend to be procured hours to minutes ahead of dispatch.
  - Some TSOs mandate that only assets with ancillary service *capacity* already contacted are eligible to participate in the ancillary service *energy* markets. Others may allow 'free bids' by assets without existing capacity contracts.

4) ***Remuneration for congestion management.*** The remuneration for relieving physical network constraints, otherwise known as 'redispatch', may vary between TSOs, both in the markets used for redispatch procurement and the pricing methodology applied. The most common pricing methodology is pay-as-bid, followed by regulated prices, but market prices such as day-ahead prices, or cost-based pricing are also used (Glowacki, 2023).

3.3.3 Market characteristics creating high prices

Due to this variation of rules and regulation across the European ancillary service markets, investors must seek information specific to the TSO to establish the potential contribution of ancillary services to the total revenues of a prospective BESS project. However, across Europe, ancillary services have historically proven to be an important source of revenue for BESS, accounting for an average of 67% until 2020 (EY, 2024). Indeed, ancillary service markets are typically subject to characteristics leading to high prices, including strategic bidding, low liquidity and limited cross zonal capacity for exchange. Further, the stability and security of an energy system is an important political imperative, making demand particularly inelastic, i.e. unchanging irrespective of price.

3.3.4 European Commission regulation driving harmonisation

2017 EB regulation mandated the creation of new platforms to harmonise the procurement of energy for the core ancillary services across Europe. The process of establishing common markets is ongoing, with TSOs gradually joining the platforms to procure their frequency and balancing energy. The overarching objectives of market harmonisation are the promotion of efficiency within markets and the smooth exchange of balancing energy across borders, in part helping to address characteristics that have driven higher prices thus far; in theory, harmonisation will increase transparency, promoting effective competition and new entrants, non-discriminatory trading, increasing liquidity all whilst maintaining security of supply (ENTSOE, 2021, 2025a; Next Kraftwerke, No Date).

Early results following the initial stages of market harmonisation have been mixed. Pan-European platforms have continued to experience occasional periods with price spikes, but the platforms are broadly considered a success. Beyond the key pan-European ancillary service energy markets, markers of success have also been observed in the Nordic market for common procurement of aFRR capacity. Launched in 2022, a transfer of capacity from regions of higher liquidity to those of lower liquidity has been observed, as has increased competition resulting in lower average aFRR capacity prices and reduced price volatility across the Nordic bidding zones (ENTSOE, 2024). Broadly speaking, as the number of TSOs signed up to common ancillary service platforms increases, the aggregate volume of necessary capacity and activated energy across Europe should decrease, as should prices and their volatility. This regulatory drive towards market harmonisation should increase socioeconomic welfare across Europe, a highly desirable outcome for consumers.

From the perspective of the EIB, the harmonisation of markets *should gradually* result in the standardisation of rules and regulation across the core European ancillary services, reducing the complexity faced during a financial assessment, particularly when comparing a variety of proposed projects in different member states.

Specifically, the likely reduction of prices arising from this regulatory change should be carefully considered; **understanding if a TSO is already an operational member of a pan-European ancillary service platform, and if not, when they are likely to join, may be important to the financial assessment of a BESS project which is predicated upon ancillary service revenues.** Box 1, below, provides an overview of the main pan-European platforms for the procurement of ancillary services. For further detail on the pan-European platforms, including TSO membership and accession roadmaps:

- For **FCR**, see (ENTSOE, 2025a)
- For **aFRR**, see (ENTSOE, 2025c; PICASSO member TSOs and ENTSOE, 2025)
- For **mFRR**, see (ENTSOE, 2025b; MARI member TSOs and ENTSOE, 2025)

INFORMATION BOX: PAN-EUROPEAN ANCILLARY SERVICE PLATFORMS

The FCR Cooperation

- A common market for the procurement and exchange of FCR capacities, which currently involves 12 TSOs from 9 countries.
- A common merit order list created from pooled offers, but contracts remain bilateral between BSPs and TSOs. Symmetrical products are procured at once (equal capacity for up and down).
- Price convergence across participating TSOs between 2017 and 2021, and downwards trend for FCR prices due to new market entrants increasing competition, except in Belgium and the Netherlands for which the transition to marginal pricing caused price increases, and import limits caused price decoupling. 2021 saw higher prices in alignment with generally high electricity prices across Europe, but price hikes slowed in 2022 and by 2023 prices returned to levels at 2021 end/ 2022 start.

aFRR platform (PICASSO project)

- The Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO) is a common platform for the procurement of aFRR *energy*.
- Operational since 2022, the platform currently has 26 TSO members and 4 observers.
- The platform experienced some teething issues, with some price spikes observed, after which the Italian TSO Terna withdrew from the platform in 2024, triggering other TSOs to postpone joining. Terna is scheduled to rejoin the platform in 2025.
- Common platforms for aFRR *capacity* include ALPACA, a German-Austrian aFRR balancing capacity cooperation, and the Nordic aFRR capacity market.

mFRR platform (MARI project)

- The Manually Activated Reserves Initiative (MARI), a common platform for the procurement and exchange of mFRR *energy*.
- Operational from 2022, the initiative has 29 member TSOs and 5 observers, including ENTSO-E. 6 TSOs are currently connected to the platform.
- The participation of all EU TSOs from all synchronous areas (as instructed by EU EB regulation), makes the MARI project the largest in terms of number of TSOs involved.

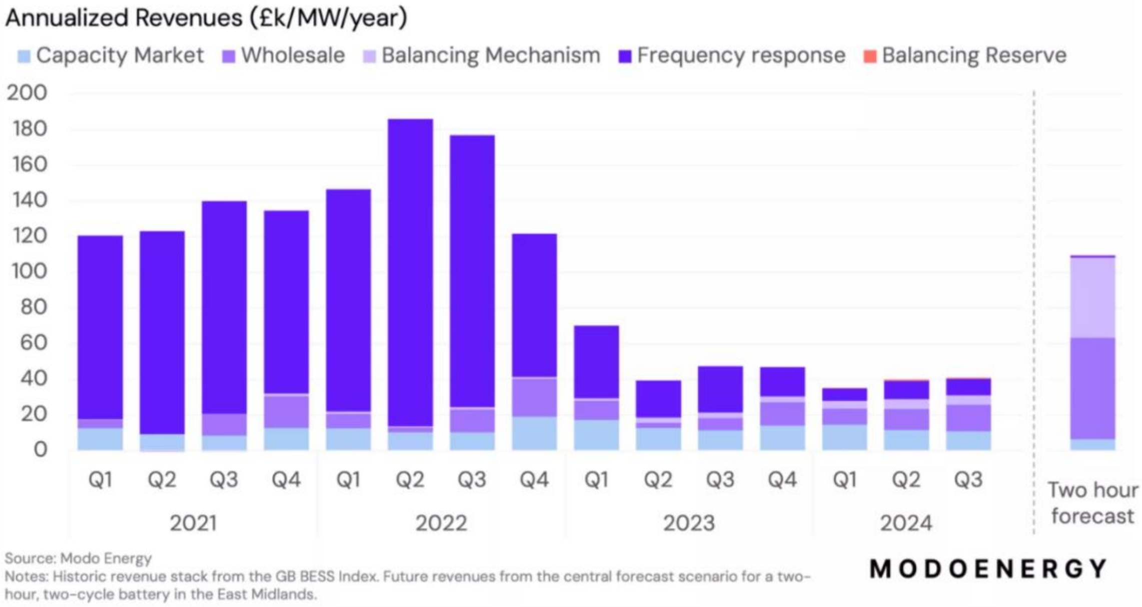
RR platform (The Trans-European Replacement Reserves Exchange, or TERRE project)

- TERRE is responsible for the implementation of the common platform for RR procurement, which was first operational in 2020.
- Despite the fact that the TERRE platform fulfilled TSO needs more than 91% of the time, it will be forced to close in 2026 due to Electricity Market Design Reform (EMDR).

Box 1: Information on the pan-European platforms for the common procurement of ancillary services. Sources: ENTSOE (2021, 2024).

3.3.5 Ancillary service market saturation and 'revenue cannibalisation'

Aside from the move to harmonised markets and the associated price reductions that are expected, an important trend in *national markets* is also emerging. Despite having historically accounted for a high proportion of the total revenues (where TSOs have allowed BESS to participate), the ancillary services are proving to be relatively shallow markets, resulting in a high risk of saturation and price cannibalisation. Whilst no longer an EU member state, Great Britain is the leading European market for utility-scale BESS deployment, therefore may be used by the EU as useful point of reference where emerging trends are concerned. This is the case for rapid saturation of frequency response markets, as is illustrated by Modo Energy (2024d) in Figure 9.



Source: Modo Energy
Notes: Historic revenue stack from the GB BESS Index. Future revenues from the central forecast scenario for a two-hour, two-cycle battery in the East Midlands.

Figure 9: The rapid reduction in frequency response revenues in Great Britain between 2021 and 2024. Source: Modo Energy (2024d).

In 2022, a staggering 84% of revenues for BESS in Great Britain were for frequency response. Within the following two years, BESS deployment in Great Britain accelerated, with a tripling of total installed capacity, as shown by Modo Energy (2025b) in Figure 10. During the same period, the demand for ancillary services only expanded by 50%, resulting in a saturated frequency market. Revenues rapidly cannibalised, with BESS projects experiencing a 7-fold decrease in prices by 2024. Now, frequency response accounts for only around 20% of total revenues. The Great British experience proves just how vulnerable frequency response markets are to saturation, with such a small capacity of flexibility required to manage system frequency compared with the total size of the system.[5]

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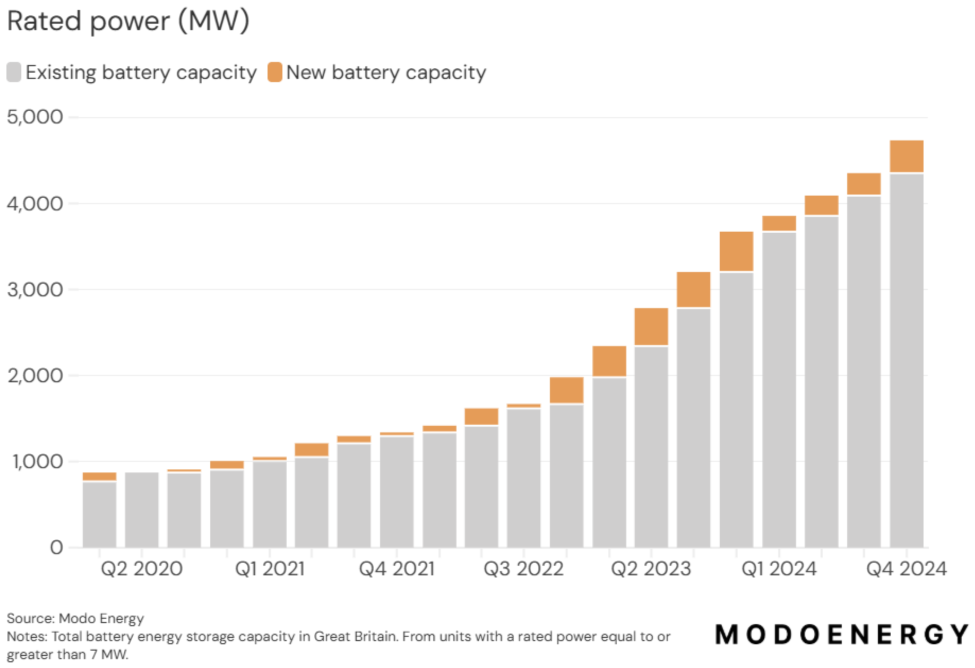
[5] During 2024, the total installed capacity of BESS reached 4 GW. Total demand on the electricity system in 2024 ranged from around 15 to 45 GW throughout the year.



Source: Modo Energy
Notes: Total battery energy storage capacity in Great Britain. From units with a rated power equal to or greater than 7 MW.

Figure 10: The rise in total grid-scale BESS capacity in Great Britain between 2020 and 2024. Source: Modo Energy (2025b).

Of course, the total demand for frequency response services is context dependent, with larger systems generally requiring a greater total capacity to maintain system stability. Hence the two largest electricity systems in Europe (measured by total electricity production (IEA, 2024b)), the German and French, generally exhibit deeper markets for frequency response. But as shown in Table 1, in 2021, the total FCR demand in Germany and France still only amounted to 562 and 508 MW, respectively. Across the entire continental European synchronous area, 3 GW of capacity is procured (Amprion, No date).

Table 1: Demand of country in the regional FCR market in 2021. Source: gridX (2024) via ENTSO-E.

Country in FCR cooperation	FCR initial demand (MW)
Austria	71
Germany	562
France	508
Switzerland	67
Belgium	87
Netherlands	114
West Denmark	20
Slovenia	15

The saturation of frequency response markets has not been limited to Great Britain. In Sweden, FCR-D[6] prices have historically been the most attractive market, and in 2022, prices were at an all-time high (Aurora, 2025f). This was partly driven by the gas crisis raising opportunity costs for gas plants participating in both the wholesale and frequency markets. A combination of favourable ancillary service prices and supportive market reforms encouraged BESS deployment, particularly of shorter duration batteries (0-1hr). Sweden's FCR-D prices then dropped over two consecutive years, reaching record lows in 2024. While lower gas and hydropower prices contributed to the reduction of revenues in this market, the rise of cheaper BESS, displacing both technologies, has also been a key driver.

Thus far, examples of saturation have been seen in 'frequency-only' markets, i.e. FCR, rather than the ancillary services in which greater volumes of 'balancing energy' are also procured. With greater market depth, it is plausible that the FRR markets will be less susceptible to saturation than the FCR.

Nonetheless, modelling conducted by Clean Horizon Consulting projects decreasing aFRR (automatic frequency restoration reserve) capacity energy prices within the remainder the decade and into the beginning of the next, with the former tending to saturate faster than the latter (Energy Storage News, 2024b).[7] Clean Horizon report that the particularly rapid cannibalisation of aFRR capacity markets is down to high participation from the BESS assets installed, ultimately due to the fact power, rather than energy, is traded. This means that a BESS asset earns revenue while reserving its energy to generate additional revenue by discharging in another market later the same day. Germany and France, the two deepest markets in Europe, are included within the Clean Horizon projections shown in Figure 11, and are no exception to this trend. Clean Horizon assume participation in the pan-European aFRR energy platform (PICASSO), which may also contribute toward the reduction of prices observed. Aurora (2025e) corroborates this finding, reporting that France's growing battery fleet will, by 2030, create significant saturation risks within its only recently opened aFRR markets, projecting a 179% ratio of total installed BESS capacity to aFRR procured capacity.

Whilst the ancillary services may prove a lucrative revenue stream in TSOs with BESS markets in their infancy, their inherently shallow nature, alongside the move towards harmonising the European markets, point to a high risk of cannibalisation. Trends observed thus far suggest that the longer-term revenues from this stream may prove relatively meagre.

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[6] In the Nordics, variants of FCR markets may be found. FCR-N (frequency containment reserves for normal operation) maintain system frequency within a normal range of 49.9Hz to 50.1 Hz, where FCR-D markets (frequency containment reserve for disturbances') respond when frequency falls outside of said range.

[7] Clean Horizon model price cannibalisation is based on aFRR activation volumes, merit order curves and BESS deployment.

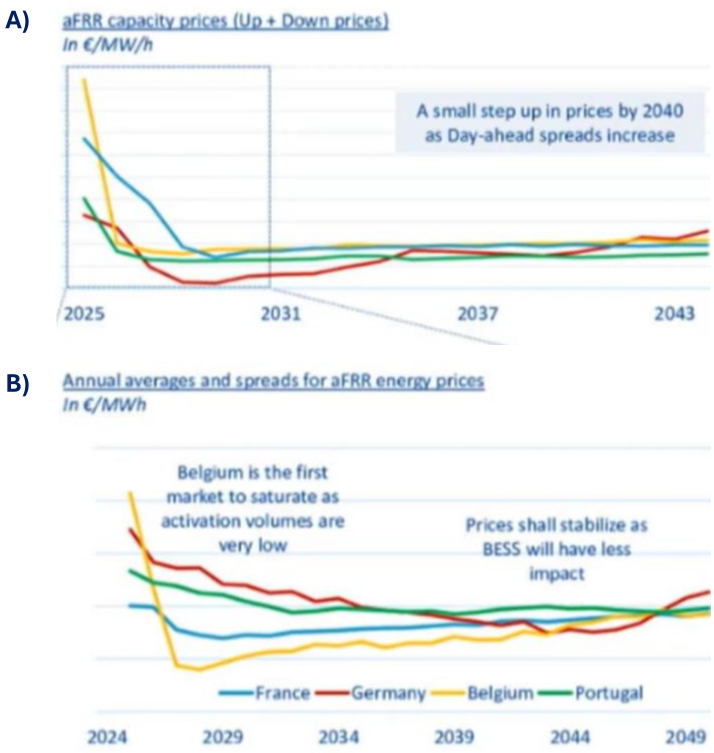


Figure 11: Clean Horizon modelling projections of A) aFRR capacity prices, and B) annual average aFRR energy prices in France, Germany, Belgium and Portugal. Source: Energy Storage News (2024b).

3.3.6 Methodological illustration: charting factors impacting ancillary service revenues using systems mapping

As has been illustrated, the future of BESS revenues, under the ancillary services stream particularly, are subject to significant uncertainty. It is therefore essential to take a dynamic approach to the financial appraisal of BESS. A participatory system mapping approach, as introduced in Section 3.2, is applied in this report to identify the key variables and dynamics to consider when evaluating a prospective project's revenue outlook. Under the ancillary services revenue stream, two maps are presented, one for each of frequency response and balancing energy. The key variables are discussed below the system maps. For a guide to reading the system maps, please refer to Annex 2: The participatory system mapping approach.

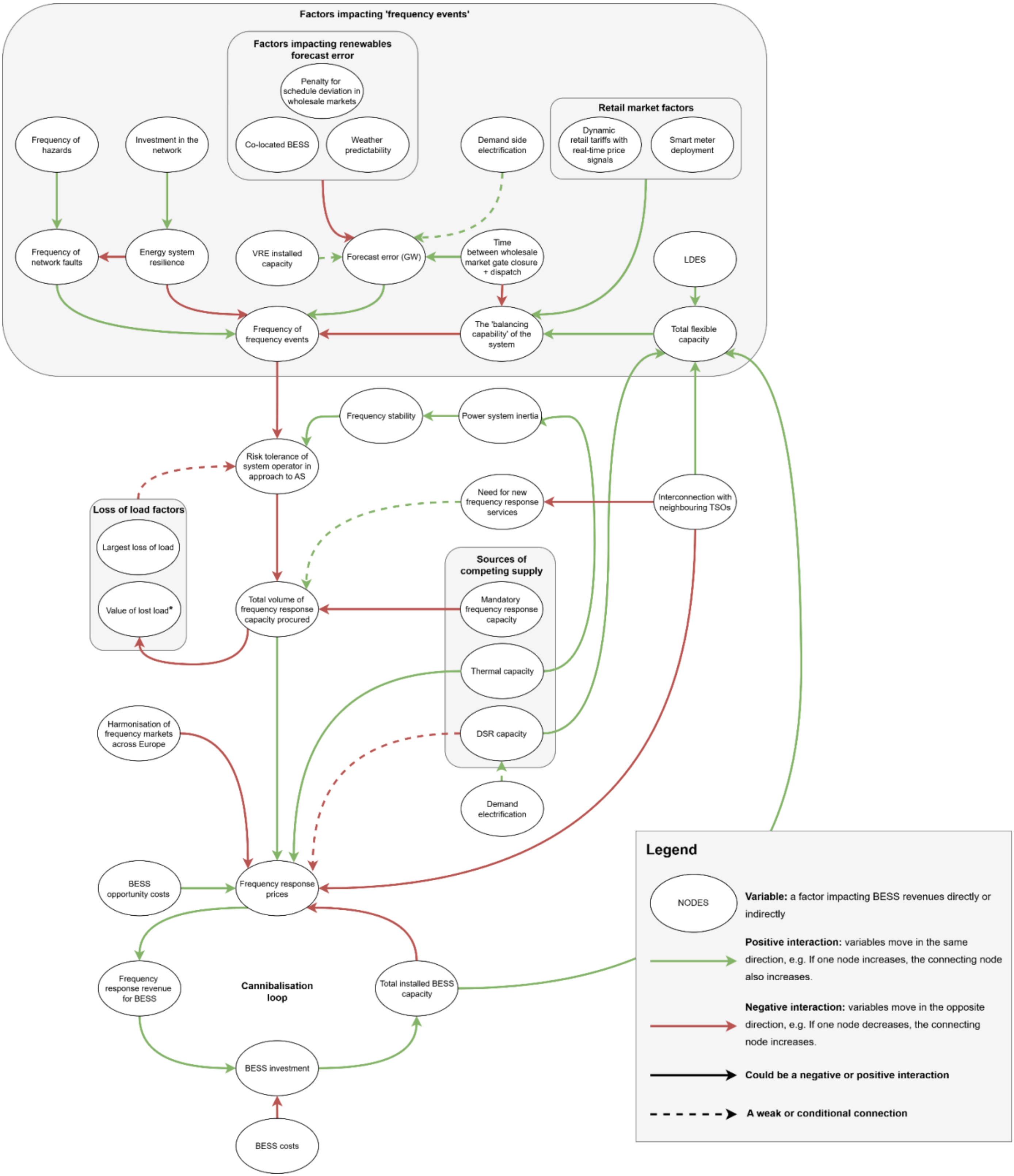


Figure 12: System map illustrating the 'factors' impacting BESS frequnecy response revenues. The factors are variables, represented by the nodes, and may be impacted by future decarbonisation scenarios and electricity market reforms at the European level, and within each TSO. Interactions between the factors are depicted by arrows. Positive interactions (green arrows) represent variables moving in the same direction, i.e. if one variable were to increase, the connected variable would also increase. Negative interactions (red arrows) represent variables moving in opposite directions, i.e. if one variable were to increase, the other would decrease. Dashed arrows represent interactions that are either weak or conditional. Black arrows represent interactions that may be both positive or negative, or that remain uncertain. Note that there are two nodes representing demand side electrification to avoid overalpping arrows reducing map clarity. For more detailed explanation of system mapping, please refer to Section 0, the Annex 2: The participatory system mapping approach.

3.3.6.1 Factors impacting future frequency response revenues

The drivers of frequency events. The system map (Figure 12) starts by identifying the factors determining the frequency of ‘frequency events’, i.e. frequency disturbances, going forwards. Some factors fundamental to decarbonisation, such as rising renewables capacity, are likely to increase the frequency of ‘frequency events’. Other factors identified could, however, help to mitigate this.

Many factors are country specific, and will hinge on regulation, levels of investment or rates of technology deployment. Overall, should the frequency of ‘frequency events’ rise, experts indicated that the risk tolerance of the system operator (SO) would decrease, thereby increasing the total volume of frequency response capacity procured. This increase in market depth would see prices rise.

The factors determining the frequency of ‘frequency events’ include:

- **The frequency of hazards**, for example fires or floods, which may cause **network faults**. Scenarios suggest that accelerating climate change will increase the regularity of such hazards, thereby increasing the frequency of frequency events.
- **Investment in the network,** however, could help to mitigate the risk of network faults by increasing **energy system resilience**. Applying the Arup (2019) definition, energy system resilience is “the ability of an energy system to reduce the impact of shocks and stresses, including the capacity to anticipate, absorb, adapt to, and rapidly recover from such events and to transform where necessary”. Investment in the network could, therefore, reduce the frequency of frequency events.
- **Forecast error**, creating an imbalance of supply and demand, is another key driver of frequency events. The greater the total **installed capacity of variable renewable energy (VRE)** on the system, the greater the potential for forecast error (in GW) as a higher proportion of total generation is met by sources dependent on changeable weather conditions.
    - Three key factors impacting **renewables forecast error** were identified:
        - The uptake of **co-located BESS** could reduce forecast error, allowing VRE generators to maintain their scheduled output by charging or discharging their connected batteries to mitigate unforeseen weather.
        - Better **weather predictability** would reduce renewables forecast error.
        - Markets with greater **penalties for generators deviating from schedule** provide greater the financial incentives for VRE to reduce their forecast error.
    - **Demand side electrification** increases the total load on the system, increasing the potential for ***demand forecast error*** (in GW), and thereby total forecast error. This is labelled in the system map as a weaker/conditional

    interaction; demand side electrification *in conjunction with* smart technologies could perhaps help to reduce forecast error.
  - The **time window between gate closure and energy dispatch** in the wholesale markets also impacts the likelihood of forecast errors; markets with a shorter window are less likely to experience unforeseen deviations in supply and demand.
- A shorter window between gate closure and dispatch also increases the overall **balancing capability of the wholesale market** and therefore overall energy system, which reduces the frequency of frequency events. Several **retail market factors** also impact the balancing capability of the energy system by facilitating demand side response, i.e. energy shifting by end-use consumers. Examples include:
  - The availability and uptake of **dynamic tariffs with real time price signals**, and
  - The deployment of **smart meters** which relay real time price signals
- The greater the **total capacity of flexibility** on the system, from the deployment of long duration energy storage (LDES), BESS, DSR, and interconnection, the greater the system's balancing capability, helping to reduce the frequency of frequency events.

Power system inertia. A reduction in power system inertia is expected as the installed capacity of thermal generators on the system decreases. This will reduce frequency stability and hence reduce the risk tolerance of the SO, increasing the capacity of frequency response procured. This will increase market depth, tending to increase frequency response prices and therefore BESS revenues.

Loss of load factors. At present, the calculation determining the volume of frequency response capacity procured is often deterministic, based on the **largest loss of load,** i.e. the potential loss of load occurring if the generator of greatest capacity were to unexpectedly come offline. The greater the largest loss of load, the lower the risk tolerance of the SO, and the greater the frequency response capacity procured. Equally, if the SO decides to increase the capacity of frequency response procured for other reasons (e.g. rising frequency of 'frequency events' or reduced inertia on the system), the **relative value of lost load** would be smaller, increasing the SO's risk tolerance. Workshops revealed that the move from large traditional thermal plants to more distributed resources may ultimately render this deterministic methodology less useful. Therefore, as the energy system transitions, the 'loss of load' factors may become less influential in the SO's approach to frequency response procurement, hence it is represented as a weak/conditional interaction.

Mandatory frequency response. In many member states, generators and/or other assets are mandated to reserve a portion of their capacity for frequency response. The greater the proportion of total frequency response capacity that procured via mandates, the smaller the volume that must be procured via an FCR market, for example. This would reduce market depth and hence market remuneration for frequency response.

New frequency response services. Decreasing levels of inertia and the potential for an increase in the regularity of 'frequency events' may result in new frequency response products being trialled and procured by TSOs. Workshops indicated that these are likely to be *additional,* thereby increasing the total market depth for frequency response services, increasing prices and BESS revenue opportunities. The procurement of new frequency response services is more likely in regions that are less interconnected, such as Ireland.

Factors directly impacting frequency response prices. The factors explored above interact *indirectly* with frequency response prices; they ultimately influence the total capacity of frequency response procured by the SO. An increase in capacity procured by the SO (i.e. market depth) will tend to increase prices and therefore BESS revenues.

Considering the factors covered thus far, the workshop revealed that on balance, there should be a modest increase in the capacity of frequency response procured by the SO as energy systems transition.

However, the system map also identifies numerous factors *directly* impacting frequency response prices, likely to mitigate the impact of a marginally deeper market. The **harmonisation of the ancillary service markets** across Europe is likely to reduce prices, as was discussed in Section 3.3.4. Linked to this is **the degree of interconnection between neighbouring TSOs**. The greater the degree of interconnection, the greater the level of competition and the more efficiently frequency response capacity can be allocated, driving down prices. Without sufficient interconnection, the impact of harmonised markets is limited.

Another group of factors are **competing sources of supply**. As long as thermal assets provide some frequency response, prices should remain higher, but as the capacity of lower cost flexibility on the system increases, for example DSR, frequency response prices are likely to fall. The greater the degree of demand side electrification, the greater the supply of low-cost flexibility on the system. However, the interaction between DSR and prices is weak/conditional given that markets must be designed to allow DSR access, which could be dependent on the aggregation of domestic consumers, for example. Of course, another lower cost source of flexibility is indeed utility scale BESS.

The cannibalisation loop. Indeed, the cannibalisation loop shows the price deflating impact of increasing **BESS capacity**. A system at first exhibiting higher frequency response prices creates higher BESS revenues, driving investment in and deployment of the technology, which in turn reduces prices. This interaction has already been observed in Great Britain, as was detailed in Section 3.3.5. Due to the inherently shallow nature of frequency response markets, only a relatively small capacity of BESS is needed to cannibalise revenues under this stream.

A **reduction in BESS costs**, driven by factors explored in Section 2, has also proven to accelerate investment in utility-scale BESS, further accelerating this cannibalisation loop. The workshops confirmed that the BESS capacity required to fulfil a full range of system services as we decarbonise is likely to far out way the future depth of frequency response markets. Therefore, revenues under this stream are unlikely to be significant in the longer term.

The final factor identified is **BESS opportunity costs**. Once the frequency response markets have saturated due to the rise in BESS deployment, the price will increasingly be set by BESS opportunity costs, i.e. BESS may bid into frequency response markets at the level of revenues possible if the asset were to participate in another market offering higher revenue potential. However, periods in which frequency response prices are inflated due to opportunity costs will inherently emerge during hours where high revenues are achievable in other markets, therefore it is uncertain whether this factor would result in any additional revenue generating opportunity for BESS.

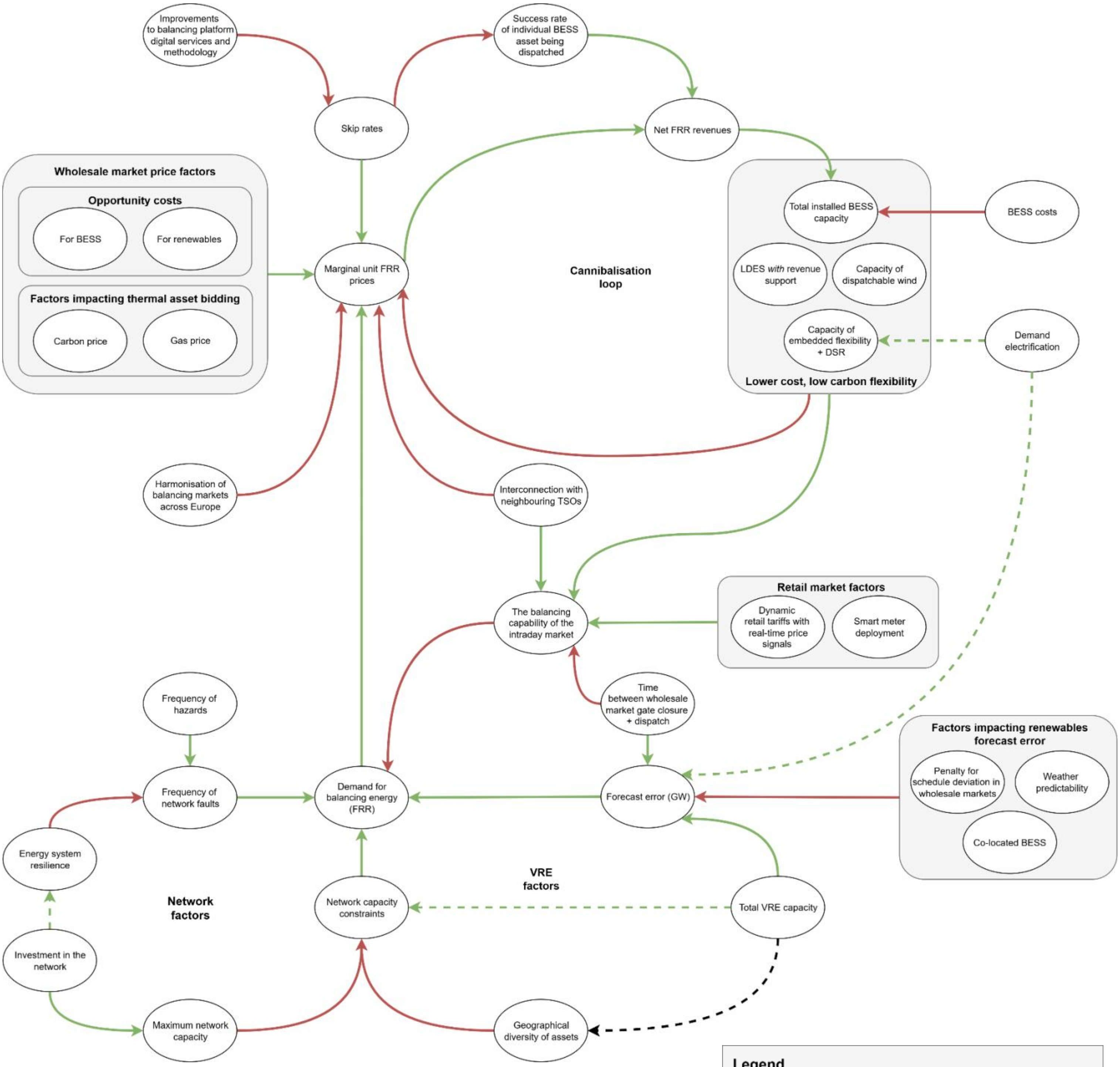
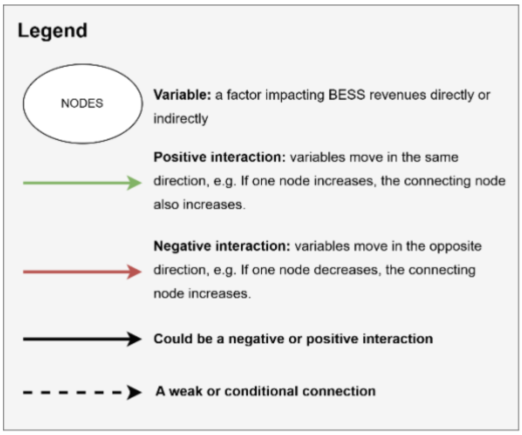


Figure 13: System map illustrating the 'factors' impacting BESS balancing energy revenues. The factors are variables, represented by the nodes, and may be impacted by future decarbonisation scenarios and electricity market reforms at the European level, and within each TSO. Interactions between the factors are depicted by arrows. Positive interactions (green arrows) represent variables moving in the same direction, i.e. if one variable were to increase, the connected variable would also increase. Negative interactions (red arrows) represent variables moving in opposite directions, i.e. if one variable were to increase, the other would decrease. Dashed arrows represent interactions that are either weak or conditional. Black arrows represent interactions that may be both positive or negative, or that remain uncertain. For more detailed explanation of system mapping, please refer to Section 0, the Annex 2: The participatory system mapping approach.



3.3.6.2 Factors impacting future balancing energy revenues

In this map (Figure 13), the balancing markets are referred to as the FRR (frequency restoration reserve) markets, where balancing energy, including the energy for congestion management, are procured in many European contexts. Numerous factors impacting BESS revenues for ‘frequency response’ were also found to impact revenues for ‘balancing energy’. Where those factors exhibit similar interactions to those already described in section 3.3.6.1, we will highlight their presence in the map, but refrain from duplicating explanations.

The drivers of demand for balancing energy in the FRR markets.

Network factors. This balancing energy system map exhibits several of the same factors related to physical networks as the frequency response map, which impact the total demand for balancing energy, i.e. market depth. The greater the **frequency of network faults**, the greater the **total demand for balancing energy (FRR)** will be. Similarly to the frequency response map, factors such as the **frequency of hazards**, **energy system resilience** and **investment in the network** all impact the frequency of network faults.

The **maximum capacity of the physical networks in an energy system** is a factor unique to the balancing map. Networks of insufficient capacity to transport electricity from the location of supply to the location of demand increase the total demand for balancing energy (FRR), as assets behind constraints are required to reduce their output, while assets in front of constraints are paid to increase their output. This interaction is particularly important in systems where generation assets are located far from centres of demand. Investment in the network can increase their total capacity, thereby reducing the total demand for balancing energy (FRR).

VRE factors. In general, increasing total **VRE capacity** on an energy system will tend to place additional strain on networks, increasing the demand for balancing energy. This, though, is dependent on the exact location of the asset hence the weak/conditional interaction. Depending on the chosen location of new VRE assets, they can either exacerbate network constraints or help to reduce strain relative to other possible sites. Experts chose to represent this as an additional interaction in the map, as a black dashed arrow between total VRE capacity and the **geographical diversity of assets** (indicating the possibility for a positive or negative interaction).

Similarly to the frequency response map, increasing **total VRE capacity** will increase the likely **forecast error (in GW)**, thereby increasing the demand for balancing energy. This map also exhibits the same set of three factors impacting **renewables forecast error**, and the same interaction between the **time window between gate closure and energy dispatch** and forecast error. Equally, the map shows that an increase in **demand side electrification** comes with the same possibility of greater forecast error (in terms of GW), a conditional on the same basis as was outlined in Section 3.3.6.1.

The balancing capability of the intraday market. A shorter window between gate closure and energy dispatch also increases the balancing capability of the intraday market.[8] Indeed, regions with nearer term intraday markets (i.e. a shorter window) will be better placed to procure energy to balance last minute fluctuations in supply and demand, compared with intraday markets operating with a greater window. The greater the balancing capability of the intraday market, the lower the demand for balancing energy in the FRR markets. Whilst this would likely translate to lower FRR prices, a rise in total demand for 'balancing energy' is, in these markets, more likely to reflect in higher and more volatile *intraday* prices. Hence, BESS revenues *might* simply shift from the ancillary services revenue stream to arbitrage.

The same **retail market factors, the degree of interconnection with neighbouring TSOs**, and **capacity of flexibility on the system (BESS, LDES, DSR and dispatchable wind)** also impact the balancing ability of the intraday market, and hence total demand for balancing energy in the FRR markets.

On balance, as VRE deployment rises, the likelihood of forecast error increasing (in GW terms) appears high, as does the potential for rising network constraints, although the latter is highly context dependent.[9] Total demand for FRR is, therefore, likely to increase. However, the depth of balancing markets should remain orders of magnitude lower than the depth of wholesale markets (LCP Delta and Regen, 2024). Further, a combination of investment in physical networks, and several factors helping to increase the balancing capability of the intraday markets, could well temper the rise in demand for FRR energy. The EIB should monitor this full set of factors in regions of interest to establish the likely change to FRR demand.

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[8] In the balancing map, the balancing ability of specifically the *intraday market* is stipulated, rather than the balancing ability of the broader energy system. This is due to the more direct relationship between the design of the intraday market with the volume of balancing energy (FRR) procured. The more balancing energy that can be procured in the intraday market, the lower the likely demand for balancing energy in the FRR.

[9] The degree of network congestion may vary depending on the location of renewables supply and demand centres, specific to individual contexts, but also the mechanism for remunerating congestion management may vary by TSO.

Factors directly impacting FRR prices.

Obeying the laws of supply and demand, the system map presents a positive interaction between **demand for balancing energy (in the FRR markets)** and resulting prices; the greater the demand, the higher that prices will be. Akin to the frequency response system map, the **harmonisation of balancing markets** would drive down prices, as would an increase in **interconnection with neighbouring TSOs**.

Wholesale market price factors. The higher the price at which thermal assets bid into the FRR market, the higher prices are likely to be. Therefore, the **carbon price** and **gas price** were listed as key factors impacting marginal unit FRR prices. In a system with significant reliance on another fossil fuel commodity, such as coal, its price would also be a relevant factor. The **opportunity costs** faced by other assets, such as BESS and renewables, were also identified as important factors impacting FRR prices. For example, BESS assets may face high opportunity costs if choosing between dispatching energy in an FRR market characterised by lower prices as opposed to a wholesale market experiencing higher prices. The BESS asset would likely bid into the FRR market at a level matching the potential remuneration available in other markets. Hence the higher the opportunity costs faced by assets for foregoing potential revenues in other markets, the higher FRR prices are likely to be. However, as was explained in Section 3.3.6.1, the ability of BESS' opportunity costs to improve its revenue outlook is highly uncertain.

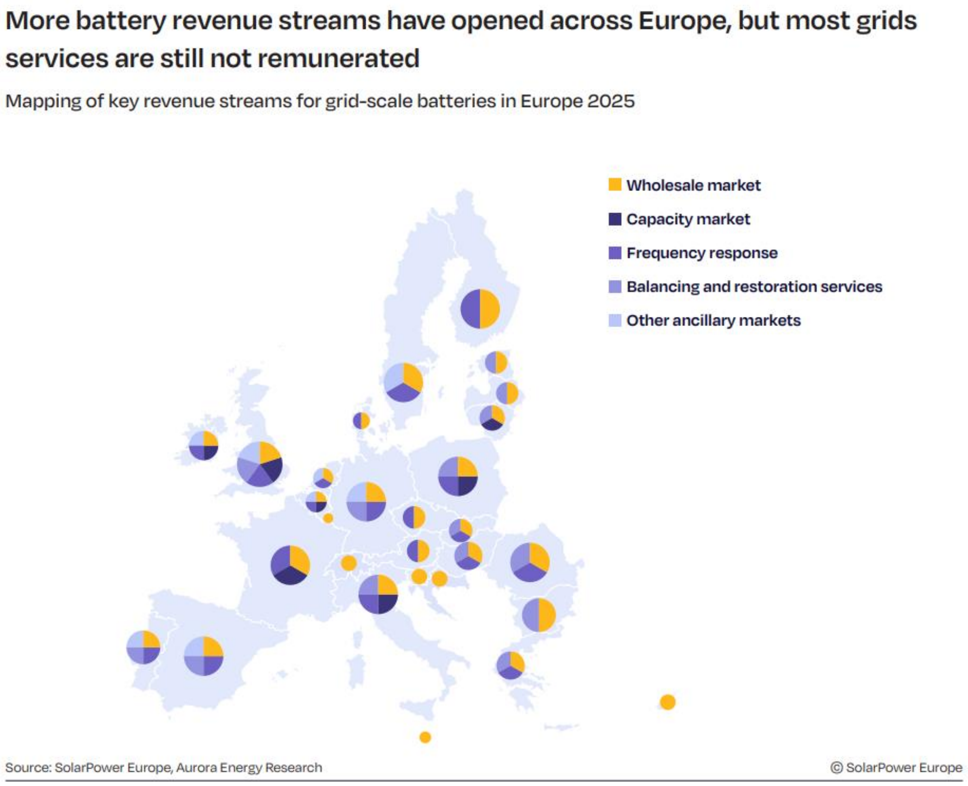
Skip rates. The 'skip rate' is frequency with which a non-economic dispatch decision is made, for example dispatching a more expensive thermal asset as opposed to a cheaper BESS asset to balance the system (NESO, 2024). In Great Britain, the outdated SO digital systems and methodology used to balance the energy system, for example lack of precedent for dispatching multiple smaller assets compared with one larger asset, have led to BESS skip rates as high as 90% (in 2023) (Modo Energy, 2024f). The higher the skip rate, the higher FRR prices will be. However, the higher the skip rate, the lower the **likelihood of BESS assets being dispatched,** reducing overall FRR revenues for BESS assets. **Improvements to balancing platform digital services and methodology** can help to mitigate this.

The cannibalisation loop. Finally, the balancing energy system map exhibits a cannibalisation loop akin to the frequency response map. Higher **balancing (FRR) prices** generate higher **BESS revenues**. Coupled with lower **BESS costs**, higher revenues encourage its deployment alongside as other **lower cost, low carbon sources of storage and flexibility**. In turn, this increases competition and reduces FRR prices. Depending on the depth of FRR demand relative to the total installed capacity of low-cost flexibility, this *could* eventually lead to the saturation of FRR markets, similar to that already seen in some frequency response markets.

The location of BESS assets. Not captured within the system map, but raised during workshops, is the importance of BESS asset location in its ability to profit from network capacity constraints. Locating near a network congestion point increases the likelihood of dispatch (to either charge or discharge) for system balancing. Indeed, in Great Britain, a region experiencing relatively large constraints due to mismatched location of renewables supply and centres of demand, well-located BESS assets executing optimal operational strategies may see revenues up to 18% higher than the average (Modo Energy, 2024g).The location of a prospective project should therefore be carefully considered. However, the longevity of location-based revenues is uncertain and could decrease should the location of demand centres change or should investments in additional sources of flexibility be made nearby (LCP Delta and Regen, 2024). Location-based revenues could also be severely hampered by future investment in the network.

3.3.7 Unremunerated ancillary services

The core ancillary service markets in which BESS earns revenue across many, but not all European contexts, have been presented. However, it is important to note that in numerous geographies there are additional system services that BESS *could* provide, that are currently unremunerated. This is often the case for the services that thermal generators have thus far provided passively, such as inertia and the capability to perform a black start. Solar Power Europe (2025a) categorises these as **'other ancillary markets'**, distinct from the **'frequency response'** and **'balancing and restoration services'** that this report has explored. Only four European countries, Germany, Portugal, Spain and the United Kingdom, remunerate BESS ***across the three categories of ancillary service*** (in bold above). Figure 14 maps the European countries, depicting the combination of revenue streams currently available to grid-scale BESS, disaggregating the ancillary services into the three categories. The map also includes wholesale and capacity markets, which are explored in sections 3.4 and 3.5 respectively.



More battery revenue streams have opened across Europe, but most grids services are still not remunerated

Mapping of key revenue streams for grid-scale batteries in Europe 2025

Source: SolarPower Europe, Aurora Energy Research

© SolarPower Europe

Figure 14: Map of key revenue streams available to grid-scale BESS in Europe. Note that the size of circles does not scale with revenue generating opportunity. Source: Solar Power Europe (2025a).

As thermal generators are gradually phased out in favour of renewables, it will become increasingly important that these ‘other ancillary services’ are adequately remunerated to ensure system stability. They could provide additional revenue streams to bolster the financial outlook of a BESS project. In Great Britain for example, the system operator launched a new ‘pathfinder scheme’, in which long term stability contracts are awarded for services including inertia, reactive power and short circuit level (Modo Energy, 2023). Zenobe’s Black Hillock BESS is the first large-scale asset in receipt of said stability contract, which has ultimately facilitated the deployment of the first commercial battery with grid-forming inverters in Britian (Modo Energy, 2025a). Another example includes the German TSOs looking to remunerate BESS assets for the provision of inertia from 2026 (Energy Storage News, 2025b).

As with the core ancillary services previously outlined in this report, attention should be paid to the contracting structure and likely depth of the new markets to ensure that investments are not founded on the promise of new streams that are equally as vulnerable to saturation.

3.3.8 Summary: emerging trends and outlook for the ancillary services

1) On average across Europe, the ancillary services have historically been the most important revenue stream for utility-scale BESS. This is particularly the case for frequency response markets (e.g. FCR), but only prior to modest deployment of storage and flexibility.
2) BESS access to the ancillary service markets is not a given. For example, in Spain, BESS is not eligible to provide FCR capacity or energy.
3) The harmonisation of the ancillary service markets, driven by EU Electricity Balancing Regulation, should, as TSOs increasingly join common procurement platforms and the interconnection between regions expands, gradually reduce prices relative to their current levels.
4) The ancillary services are inherently shallow markets, particularly the FCR, and there is evidence of rapid cannibalisation of revenues with relatively modest BESS deployment.
5) Ancillary service markets may become deeper as VRE replaces thermal generation, due to factors such as rising forecast error, but growth in these markets will likely be marginal relative to the expected rise in demand for storage for energy shifting.
6) Additional frequency response products and markets may be trialled and implemented to support energy systems transition, but less-so in well interconnected regions.
7) Absolute growth in ‘balancing energy’ markets may be greater than growth in ‘frequency response’ markets but is highly dependent on the competing balancing capability of intraday markets. Intraday markets with higher balancing capability will likely see higher and more volatile prices, reflecting a rise in demand for balancing energy.
8) Demand for balancing energy for congestion management may rise if the location of renewables supply and centres of demand are increasingly misaligned. Depending on TSO-specific mechanisms to procure energy for congestion management, balancing energy revenues for BESS assets located near network congestion points may be higher. However, these higher, location-dependent revenues are susceptible to cannibalisation by neighbouring assets and future network investment.
9) Markets for currently unremunerated ancillary services may emerge as energy systems decarbonise, adding additional routes to market for BESS. The level of remuneration for new markets will depend on the procurement and pricing mechanisms adopted by TSOs, as well as market depth relative to total installed capacity of eligible storage and flexibility.

3.4 Energy arbitrage, remunerated in wholesale markets

3.4.1 What is energy arbitrage?

Energy arbitrage is the second of the three core revenue streams for utility-scale BESS in Europe. Arbitrage involves buying electricity when the price is low, storing it, and selling the electricity once prices are higher. This ‘energy shifting’ typically corresponds with charging the battery during a period of relative surplus electricity supply, and then discharging during a period of lower renewables output or higher demand when more expensive, dispatchable sources of generation are required (IRENA, 2024).

Arbitrage is conducted within or across the near-term markets, where BESS operators have a clearer view of likely weather forecasts, residual demand curves and market prices, as well as their own state of charge. This predominantly involves the wholesale markets, principally either the day ahead market or the intraday market where energy is traded on the day of dispatch. If prices are favourable, energy may also be arbitraged (bought and/or sold) within in the ancillary service markets, notably components that trade greater volumes (the mFRR or RR). Until 2020, energy arbitrage accounted for only 9% of the revenue stack for European BESS projects (EY, 2024). In recent years this share has increased, reaching 23% by 2024. This is, in part, down to ancillary service revenues declining in *some* regions, but is also due to growing price spreads.

3.4.2 The growth of price spreads in Europe

‘Price spreads’ are the difference between the price at which the electricity is bought (low prices) and sold (high prices) by the BESS; the larger the spread, the greater the revenue acquired. In recent years, the price spreads across Europe have been growing.

The drivers of low prices

Accelerating renewables deployment across many European geographies is driving price cannibalisation in wholesale markets. Their low opex, alongside support schemes, encourages bidding at very low prices. There are increasing periods in which high renewables output, alongside the generation from other inflexible sources, can meet the required level of electricity demand. In marginal pricing-based markets, this results in renewables increasingly setting wholesale prices, at low values.

There are times in which wholesale prices are not just low, but are in fact driven negative, creating even larger spreads. The drivers of negative prices include:

1) Many forms of support payments for renewables create incentives to ‘bid negative’. These include policies such as feed-in-premiums and the UK’s renewables obligation

(RO) certificates, in which payment added to the wholesale price creates the incentive to bid somewhat negative, as long as the *net* revenue is (sufficiently) positive. Earlier forms of CfDs create an incentive to bid as deeply negative as required to ensure the offtake required to get the strike price. More recent designs often incorporate 'negative pricing rules', which remove the payment if wholesale prices are negative[10], removing this distortion. However, there remain numerous generators still operational supported by earlier contracts.

2) BtM sources of generation such as rooftop solar are price insensitive and may therefore contribute to negative prices seen in the market.
3) Interconnectors transferring electricity from neighbouring regions also experiencing surplus generation may also set negative prices.
4) Finally, during periods of surplus, thermal generators may, for a limited period, bid negatively to avoid the costs associated with ramping or shutting off their power plants.

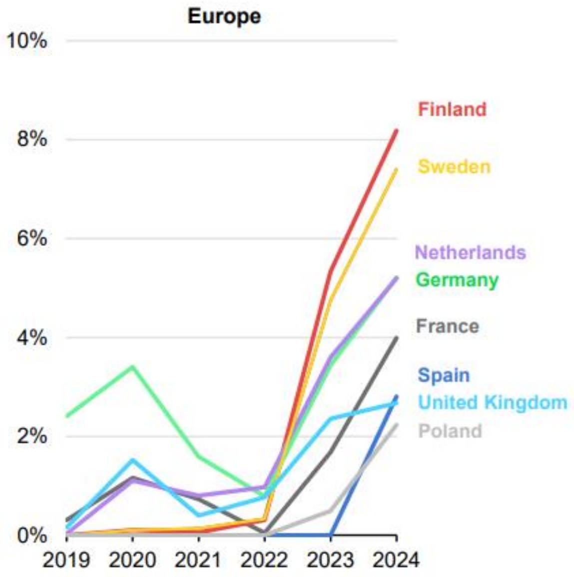


Figure 15: Fraction of negative hourly wholesale electricity prices in selected European countries, 2019-2024. Source: IEA (2025).

2024 did in fact see record breaking occurrences of negative prices across Europe, as is illustrated by the IEA (2025) in Figure 15. The most frequent were in Finland, with 721 hours of negative prices, a 54% increase compared with 2023 (Montel News, 2024). Sweden saw 720 (in the SE2 bidding zone) and 674 (SE1 bidding zone), the Netherlands 457, Germany 450 and France 350. Regions with fewer negative prices previously may

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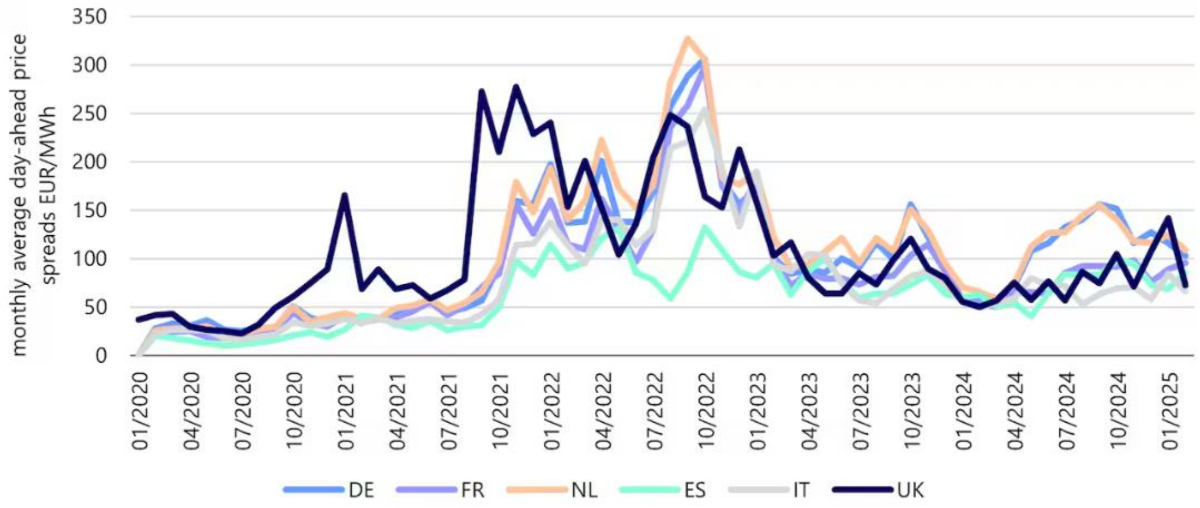
[10] In reality, whether CfD payments are made or not depends on the *reference price*. In Great Britain, the reference price is the day-ahead price, therefore if the day-ahead price settles below zero, CfD payments will no longer be made for renewables with the most recent contract design for any output sold during that time window. The choice of reference price may differ between countries.

see growth rates even higher. France, for example, saw a 138% increase in negative prices in 2024, and is observing an even steeper incline this year (Aurora, 2025d).

The role of high prices

For the creation of adequate price spreads, equally as important are the periods in which renewables cannot meet demand. During said periods, wholesale markets see higher prices as more expensive sources are called upon and become the marginal generator. Several technologies could be dispatched during said periods. Markets in which fossil fuels overwhelmingly play this role, such as Germany and the Netherlands, have observed higher 'peak prices' than others with a substantive role for e.g. PSH or nuclear, creating greater price spreads. Of course, the sizes of said spreads are highly correlated with the prices of internationally traded commodities, such as natural gas, which are characteristically volatile and have been particularly high in recent years following Russia's invasion of Ukraine. Further, markets in which coal remains a frequent price setter also bear the carbon price, likely creating even greater volatility.

In Figure 16, Rabobank (2025b) charts average price spreads in Germany, France, the Netherlands, Spain, Italy and the UK from 2020 to 2025. The ability of an asset to capture the value presented in Figure 16 will depend on asset characteristics, cycling strategy, and the duration of time across which the spreads are calculated. Hence, we use this chart purely as a means of comparison between regions to identify the indicators of higher or lower spreads, rather than to present absolute values for arbitrage revenues. Indeed, comparing the temporal evolution of price spreads across these markets, with their varying electricity mixes, demonstrates the emerging link between the fossil fuel dependence of a nation, fossil fuel price, and arbitrage opportunities for BESS.



Source: Entso-E, RaboResearch 2025

Figure 16: Monthly average price spreads on the day-ahead market from 2020 to 2025 in selected European countries. Source: Rabobank (2025b).

A combination of the 'Mechanismo Iberico' feed in tariff, implemented to reduce the cost of gas to power plants, alongside significant PSH capacity, meant that Spain did not experience such a rise in price spreads during the crisis, and has since continued to observe smaller spreads than markets more gas dependent (Timera Energy, 2024a; Rabobank, 2025a). France's nuclear fleet allows generation to broadly follow demand at lower marginal costs, therefore its markets also exhibit smaller spreads. Unfortunately timed nuclear outages during the energy crisis left France unexpectedly dependent on fossil fuels, which temporarily created much higher spreads.

Comparatively, Germany and the Netherlands are heavily reliant on fossil fuels. Both generate around 40% of their electricity from VREs but still have at least 45% of generation from a combination of gas and coal (IEA, 2023a). These markets experienced the highest spreads of all the markets during the crisis and have continued to do so since. Recent data presented by Aurora (2025a) confirms price spreads in Germany of over €100/MWh, driven by enduringly high gas prices and a growing renewable fleet. BESS revenues in Germany are their highest during the summer months; day-ahead price spreads were 27% larger in July 2024 than in January 2025 due to the duck curve effect created by high installed capacity of solar PV.

Still heavily reliant on natural gas, Italy did see an increase in spreads during the crisis, but in 'normal times' its PSH capacity helps to temper peak prices. Further, negative prices have thus far been prohibited, keeping spreads smaller than those in Germany and the Netherlands.

The impact of generation from solar versus wind on the shape of price spreads

As has been outlined, price spread fundamentals are the growing periods of low and negative prices driven by renewables, combined with sufficient periods of higher prices, likely set by fossil fuels. However, the specific *mix* of renewable generation technologies can also impact the shape and size of spreads.

Daily price spreads in regions with high solar capacity. High installed capacity of solar PV creates distinct 'duck curves'. PV generates its greatest output during the middle of the day when demand is typically low, and can thereby create surplus electricity generation and very low prices. Aurora (2025d) recently reported that the rising but still rather modest capacity of PV in France has already driven 100 hours of negative prices in 2025, dropping as low as -€115/MWh, and generally concentrated during the midday window of 10am-4pm. After the midday window, solar generation quickly tails off, meaning more expensive fossil fuels must ramp up to meet rapidly rising demand which peaks in the early evening. Therefore, the combination of high installed PV capacity with sufficient fossil fuel-based generation can create relatively predictable large price spreads, daily. This is particularly the case during the summer months when solar output is at its highest.

The impact of wind energy on price spreads. Wind does not exhibit the same pronounced *daily* patterns as solar where generation is anticorrelated with demand. In fact, markets with high installed capacity of wind, alongside some solar, may see a lower 'peak prices' during the *daily* evening peak, particularly in summer months. Indeed, wind output in the evening can reduce the reliance on fossil fuels to meet the higher levels of demand (Rabobank, 2025a). This has been the case in Great Britain, as can be seen in the post-crisis price spreads of Figure 16.

That said, in winter, geographies with higher installed capacity of wind do see an increase in their spreads compared with the summer months. Higher wind output can create low prices during periods of lower demand, while fossil fuels are more often relied upon during periods of peak demand.

Systems with particularly high wind capacity are also likely to see longer stretches of high *and* low wind output (i.e. both extended periods of surplus, *and* extended periods of renewables deficit relative to demand) (LCP Delta and Regen, 2024). Therefore, spreads in such systems are also likely to extend over longer durations than in systems with higher PV capacity.

3.4.3 Favourable conditions create high revenue potential for BESS

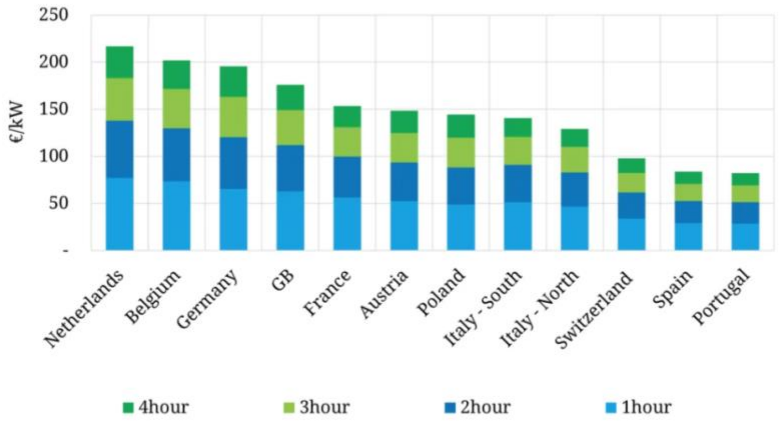
In summary, indicators of markets with large wholesale price spreads include:

- high total renewables deployment driving frequent low and negative prices, likely including relatively high installed capacity of solar, coupled with
- an enduring reliance on fossil fuels to frequently set the price during periods of high demand and/ or low renewables generation, and finally
- very few dispatchable sources such as PSH or nuclear able to balance the grid at lower cost.

Germany and the Netherlands are currently the two leading markets, observing large price spreads which are helping to create attractive markets for BESS investment (Timera Energy, 2024a; Rabobank, 2025a). Since 2021, utility scale BESS capacity in the Netherlands has increased by almost a factor of six, while in Germany it has almost tripled (Aurora, 2025a, 2025b).

Optimising BESS duration for arbitrage revenues

Unlike the BESS of far shorter durations but high rated power, better suited to provide frequency response services to the grid, BESS of longer durations are required to profit from energy arbitrage. In , Timera Energy (2024b) illustrates the additional value to be captured by increasing the duration of a BESS system from 1 up to 4 hours when conducting arbitrage in various European day ahead markets.



Source: Timera Energy; Note value calculations assume a simple D-A arbitrage capture strategy with visibility across a monthly horizon (efficiency 85%) - analysis only covers D-A value not Within-Day and other revenue streams.

Figure 17: Day ahead market energy arbitrage BESS value capture in 2022. Source: Timera Energy (2024b)

In the longer term, BESS durations up to around 4-hours may remain best suited to maximise arbitrage revenues in systems that will eventually become solar dominated, discharging over a few hours of low prices during the midday window. This may not remain the case for energy systems that will become predominantly underpinned by wind energy. The higher probability of extended periods of high and low wind, and correspondingly extended periods of low and high prices, would necessitate BESS of longer durations, or indeed other long duration storage technologies (LDES), to maximise arbitrage capture value (LCP Delta and Regen, 2024)

Most new BESS deployments globally are of duration between 1 and 2 hours. At present, batteries of shorter duration may indeed be the most profitable in many markets. However, as the ancillary services revenue stream cannibalises and arbitrage revenues become an ever more important component of total revenues, augmentation may become an increasingly attractive investment proposition. This will be aided by the continued cost reductions expected of battery cells over the coming years, as outlined in Section 2.2.4.

Box 2: Optimising BESS duration for arbitrage revenues.

3.4.4 The risk of overreliance on arbitrage

Also contributing to summer BESS profitability in Germany are higher ancillary service prices, as thermal power plants are more frequently switched off, therefore reducing competing supply for frequency and balancing services. Indeed, as promising the arbitrage revenue stream may be, in most contexts, alone, it is unlikely to be sufficient. Complementary sources of revenue will also be required to build a strong business case. BloombergNEF estimates that for BESS solely reliant on arbitrage, spreads of €114/MWh would be required for a two-hour battery at current costs (Rabobank, 2025a). If the capex of BESS were to significantly decrease, it is only in markets with spreads as high as Germany and the Netherlands where it *may* be conceivable that business cases could be built on predominantly arbitrage, but not without significant risk.

Regulatory structures, and future changes beyond storage regulation *per se*, can also have a significant impact on the financial outlook. This is illustrated by the impact of high grid fees in the Netherlands. Despite large price spreads, and access to FCR and aFRR markets not yet saturated, Dutch BESS is subject to high grid fees. Already, this hampers overall return on investment; Aurora (2025b) reports that the fees render the internal rate of return (IRR) of standalone utility-scale BESS below the weighted average cost of capital (WACC). Any further increases to grid fees, combined with the likely saturation of the ancillary service markets, *could* risk the viability of new BESS projects. This ultimately highlights the importance of revenue stream diversification even if arbitrage is highly lucrative. See Section 4.3 for a case study on the Netherlands.

As electricity is increasingly generated by variable renewables, the need for energy shifting to help balance supply and demand will only increase. The demand for energy shifting will be on the order of GW, making the market for arbitrage far deeper and less susceptible to saturation than the ancillary services.

Residual demand projections may be used to produce simplistic estimates of potential arbitrage market depth. For GB, we used a scenarios-based methodology, as described in Brown *et al.*(2024), to project hourly residual demand in 2030 under two future energy scenarios by the National Energy System Operator (NESO).[11] By 2030, in 40-51% of hours, a source of dispatchable generation, storage or flexibility, *in addition to solar PV, nuclear and on and offshore wind*, will likely be required to meet demand, depending on the scenario chosen. The *average* GW of additional electricity required during said hours sums between 12.4 and 13.5 GW. Similar scenario-based calculations may be conducted for other regions to estimate arbitrage market depth at various stages of energy system decarbonisation.

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[11] Hourly residual demand: demand unmet by solar PV, nuclear, on and offshore wind, calculated on an hourly basis. Said demand could presumably be met by forms of storage and flexibility alike. Please note that this methodology does not account for demand flexibility above present levels, which would be important to reflect if projecting arbitrage market depth beyond 2030.

But the arbitrage revenue stream is far from immune to the risks of cannibalisation; there are several additional variables to consider before relying too heavily on the promise of large price spreads. The following system map identifies a number of factors and dynamics impacting future arbitrage revenues.

3.4.5 Methodological illustration: charting factors impacting arbitrage revenues using systems mapping

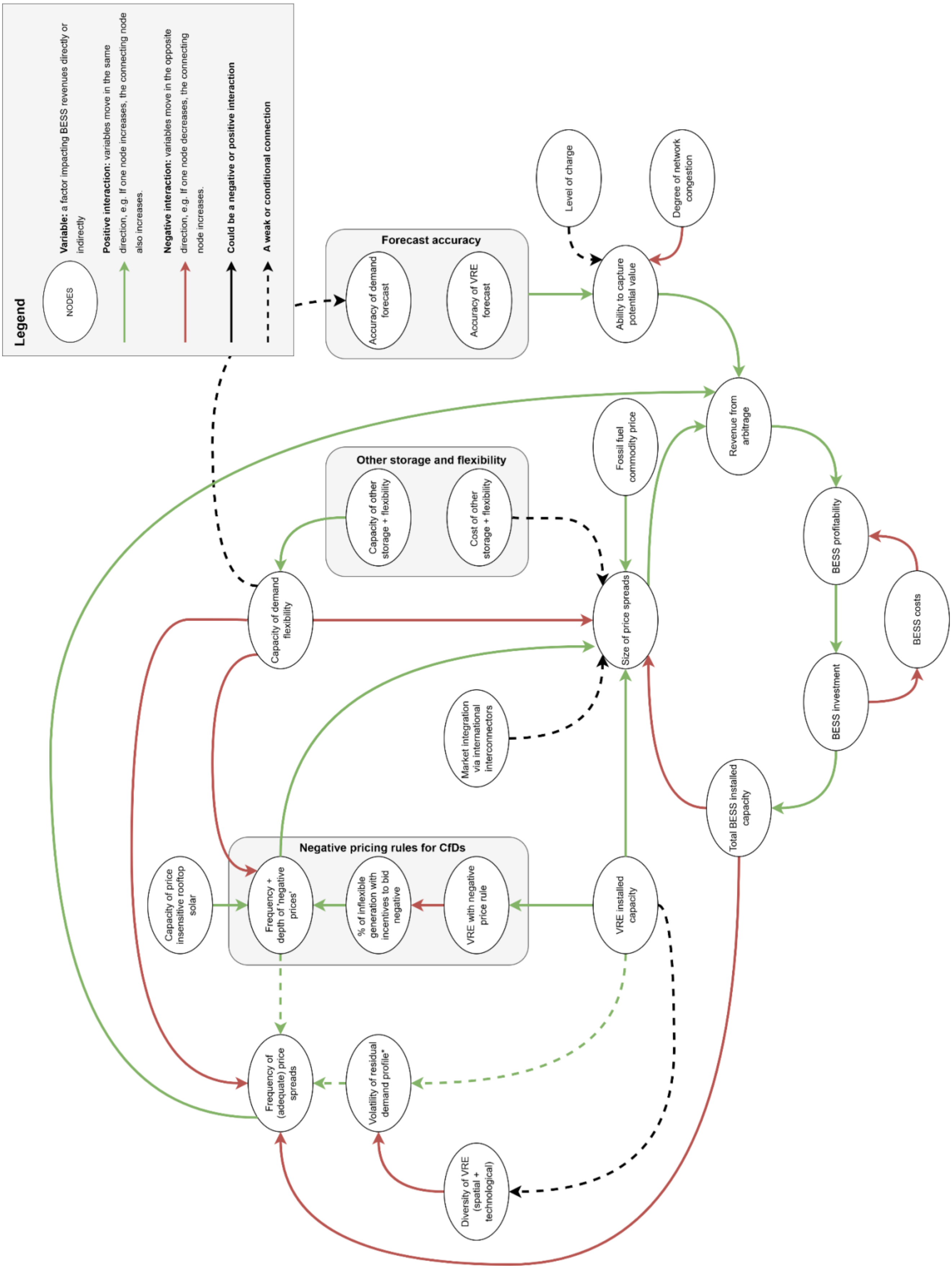

Figure 18: System map illustrating the 'factors' impacting BESS arbitrage revenues. The factors are variables, represented by the nodes, and may be impacted by future decarbonisation scenarios and electricity market reforms at the European level, and within each TSO. Interactions between the factors are depicted by arrows. Positive interactions (green arrows) represent variables moving in the same direction, i.e. if one variable were to increase, the connected variable would also increase. Negative interactions (red arrows) represent variables moving in opposite directions, i.e. if one variable were to increase, the other would decrease. Dashed arrows represent interactions that are either weak or conditional. Black arrows represent interactions that may be both positive or negative, or that remain uncertain. For more detailed explanation of system mapping, please refer to Section 0, the Annex 2: The participatory system mapping approach.

The system map (Figure 19) indicates that revenue from energy arbitrage fundamentally amounts to (a) the **size of price spreads** and (b) the **frequency of (adequate) price spreads** in the relevant markets.

- With larger price spreads, the greater the revenue accrued by a BESS asset per charging cycle.
- The greater the frequency of adequate price spreads, the greater the number of opportunities for BESS to profit from additional charging cycles.

An increase in each of these two core factors will increase **BESS revenues from arbitrage**. Experts identified numerous factors, often feeding into feeding into both the size and the frequency of price spreads, either directly or indirectly, impacting the arbitrage revenue outlook.

The scale and diversity of VRE deployment.

As has been discussed in section 0, a rise in the **installed capacity of VRE** creates instances where the output from renewables of low marginal cost is sufficient to meet demand, driving lower and negative prices in the wholesale market. The lower the wholesale price during said periods, the greater the size of price spreads.

Equally, with an increase in the periods of low and negative pricing, VRE deployment is creating more **volatile residual demand profiles**, which currently increases the frequency of price spreads. In the system map, these are labelled as weak/conditional interactions. Indeed, in the longer term, depending on the degree of renewables overbuild, it is conceivable that *further* deployment of VRE could in fact reduce the volatility of the residual demand profile. Energy systems *may* reach a state in which additional VRE would only further increase the proportion of the time in which renewables output alone meets demand, up from an already high level. This could in fact reduce the frequency of price spreads, which inherently require sufficient periods of higher prices. The **spatial and technological diversity of VRE** is also important; the higher the technological and spatial diversity, the less volatile the residual demand profile of a low carbon energy system is likely to be, given the generation profiles are less likely to be quite as strongly correlated.

Negative pricing rules for CfDs. The system map identifies a distortion caused by the design of CfDs, a common renewables support scheme. Standard two-way CfDs or RO contracts incentivise VRE to maximise total output sold to ensure the receipt of support payments. These generators may drive the price as low as the negative value of their support contracts. Earlier VRE generators are more likely to have these standard contract types and hence the incentive to drive prices negative, which increases the size of price spreads. This dynamic may currently be seen in wholesale markets. In response to this market distortion, more recent CfD contracts *may* include a ‘negative pricing rule’, which removes support payments for generators should the wholesale price drop below 0. If the total capacity of **VRE on contracts with negative pricing rules** significantly increases, the **% of VRE with the incentive to bid negative** into wholesale markets will decrease. The likely impact will be increased herding at a price of 0 in the wholesale market, reducing both the **frequency and depth of negative** (Brown *et al.*, 2024). This is likely to reduce the size of price spreads as well as the frequency of adequate price spreads, compared with the earlier VRE contract types.

An increase in VRE deployment is broadly expected to increase the size and frequency of price spreads in the shorter term. However, the system map reveals several potential future conditions amongst the VRE-related factors that *could* start to reverse or at least plateau this trend to increasing arbitrage revenues as total VRE capacity rises.

Smaller scale renewables may not be subject to the same nuance, for example as the total **capacity of price insensitive rooftop solar** in an energy system increases, the frequency and depth of negative prices is likely to increase, which will directly increase the size and the frequency of price spreads.

Fossil fuel commodity prices. As was discussed in section 0, whilst traditional thermal power plants (e.g. gas, coal) still regularly set prices in wholesale markets, the higher the **fossil fuel commodity price**, the higher the level of peak prices, which increases the size of price spreads. Internationally traded fossil fuels have historically been characterised by highly price volatility, a trend unlikely to reverse. However, for regions in which electricity prices are frequently set by gas, with EU liquid natural gas (LNG) capacity projected to exceed declining demand, a period of lower gas prices could be plausible through the backend of the 2020s (Melekh *et al.*, 2025).

The capacity of demand flexibility. The probable bidding behaviour of storage and flexibility once it regularly becomes the marginal technology in wholesale market is somewhat unknown. That said, the greater the capacity of storage (including BESS and LDES) and other demand flexibility (such as DSR), the greater the likelihood of price curve flattening, in which low prices become higher, and high prices become lower. In the case of storage, this price curve flattening occurs due to a rise in demand for electricity during periods of low prices to charge assets, and a rise in supply during higher price periods when storage seeks to discharge. Therefore, an increase in demand flexibility has the potential to decrease the size of price spreads as well as their frequency, reducing BESS revenues from arbitrage.

The cannibalisation loop. The map explicitly illustrates essentially the same cannibalising interaction as described above for broader demand flexibility, but specifically for BESS assets. The cannibalisation loop indicates that larger price spreads increase revenues from arbitrage, which increases **BESS profitability**, and thereby **BESS investment**. As the total **installed capacity of BESS** increases, both the size and frequency of price spreads decreases. BESS investment is also shown to decrease **BESS costs**, due to the exogenous factors explored in Section 2.2.1, which increases its profitability, further increasing the deployment of BESS. The system map indicates that while wholesale markets are amongst the deepest of the electricity markets, in the longer term, as investment in storage increases, price spread cannibalisation and a decline in arbitrage revenues is indeed possible.

Forecast accuracy. Experts also chose to include factors related to forecast accuracy, which ultimately impact the ability of a BESS asset to generate revenue. Experts indicated that greater **accuracy of VRE forecast and demand forecast** increase the ability of a BESS asset to optimise its operational strategy and **capture value**. An increase in demand flexibility could either increase or decrease the accuracy of demand forecasts, represented by a black dashed arrow. This interaction could, for example, depend on the degree of aggregation of the demand side, as well as the visibility and predictability of household consumption as domestic electrification takes place. The ability of a BESS asset to capture potential value also depends on the asset's **level of charge**, determined by the operational strategy. Further, the **degree of network congestion** impacts the ability of assets to capture maximum price spreads (i.e. value), for which the specific firm access rights of a BESS asset are important.

3.4.6 Summary: emerging trends and outlook for arbitrage

1) Arbitrage is becoming an increasingly important revenue stream for utility-scale BESS, now accounting for 23% of revenues, up from 9% in 2020, on average in Europe. Price spreads have been growing in numerous European geographies where:
    - VRE buildout is accelerating, generating periods of low and negative prices in wholesale markets
    - Fossil fuel generation with high commodity costs remains the marginal technology for a significant portion of hours
    - There is significant deployment of solar technologies, for which generation is anticorrelated with demand
    - There is minimal low-cost dispatchable generation or flexibility (e.g. PSH).

2) The trend of growth in the share of BESS revenues from arbitrage is generally forecast to continue, enhancing the case for investment at present. Indeed, investment in regions with more volatile wholesale markets is advised.
3) That said, over-reliance on the arbitrage revenue stream poses significant risk. Only in very few contexts are price spreads currently large enough for a viable business case, notwithstanding the uncertainties related to future arbitrage revenues identified in the participatory system mapping exercises, including:
    - Future fossil fuel commodity prices
    - The level of peak prices when fossil fuel generation no longer regularly sets prices, presumably set by dispatchable low-carbon assets including storage
    - The possibility of price curve flattening due to accelerating storage deployment, i.e. the risk of price spread cannibalisation due to assets performing arbitrage
4) Additional uncertainties, requiring further research, relating to the longer-term impact of further VRE deployment on arbitrage revenues were also identified, including:
    - Distortions created by renewables support schemes impacting the size of price spreads
    - The technological and spatial diversity of VRE impacting residual demand curves and hence the frequency of opportunities for battery cycling
    - The degree of VRE overbuild impacting residual demand curves and battery cycling opportunities
5) There may be increasing feedback between arbitrage revenues and ancillary service revenues. If wholesale markets exhibit high price spreads, ancillary service prices may be driven up, even if markets are saturated. This is due to the opportunity costs of providing ancillary services rather than conducting energy arbitrage being higher.

3.5 Capacity markets

3.5.1 What are capacity markets?

Capacity markets, where adopted, offer a third core revenue stream for utility-scale BESS in Europe. They are markets dedicated to ensuring that there is always sufficient capacity to meet peak demand by remunerating assets for their availability. There are only six capacity markets in Europe thus far, in Great Britain, France, Italy, Poland, Belgium and Ireland, but the potential implementation of a capacity market is under active consideration in eight further countries.[12]

Capacity markets were originally designed to encourage investment in new thermal assets when wholesale markets, alone, were found to be insufficient to incentivise the adequate energy security. While the fundamental objective of a capacity market remains the same, decarbonisation goals within Europe mandate the transformation of energy systems, including a shift to low carbon sources of 'capacity'. Therefore, low carbon alternatives *should* gradually displace the incumbent thermal generators that have traditionally been remunerated by capacity markets.

All but France have opted for centralised capacity market design.[13] In a centralised capacity market, contracts are allocated to eligible assets via competitive auctions to meet a prior determined capacity target. There are typically at least two categories within a capacity market auction, the first awarding longer term contracts for new build assets, and the second offering shorter term contracts for existing assets (Müller *et al.*, 2024). European capacity markets currently operate pay as clear auctions, with some countries applying price caps to differentiate the revenues available for existing assets versus new (Aurora, 2025c).

For new BESS projects, if successful at auction, the long-term contracts can provide a consistent revenue stream over period of 10, 15 or 17 years, depending on the country. Payments are made to the successful assets for the capacity reserved (in €/MW), irrespective of whether they are ultimately required to dispatch any energy. Therefore, if the capacity market revenue stream *is* available, it provides an important degree of stability, helping to de-risk the overall business case. Further, successful assets may also participate in other markets, so long as they can fulfil the availability requirements stipulated within their capacity market contracts. According to EY (2024), capacity markets currently represent around 23% of BESS revenues in Europe.

3.5.2 Strong competition from thermal assets

Auctions are generally technology agnostic, therefore any asset demonstrating the ability dispatch energy when called upon can compete. Therefore, capacity market contracts could theoretically be awarded to a whole range of asset types, including DSR, short and

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[12] European countries currently considering capacity markets include: Spain, Greece, Sweden, Finland, Estonia, Latvia, Lithuania and Germany. A decision is expected by 2028 in Germany, while the Spanish are at an advanced stage with a capacity market expected within the next year.

[13] First operational in 2017, the French capacity market operates a decentralised model in which suppliers and large consumers are obligated to obtain capacity certificates, issued by generators, to cover their demand. This decentralised model experiences price volatility, for example in 2019, French capacity market prices dropped to zero (Timera Energy, 2020). The current model will expire in 2026, and is under review by the French TSO, RTE (RTE, No date).

long duration storage technologies, interconnectors and thermal assets. In practice, it is proving more challenging for the smaller, decentralised sources to secure contracts and accrue revenue under this stream (Aurora, 2025c).

Derating factors are used to weight the capacity (i.e. expected statistical availability if and when called upon) provided by various asset types (Modo Energy, 2024b), so as to reflect the expected reliability and value of an asset during a ‘stress event’. A stress event is a period in which supply in wholesale markets looks unlikely to meet demand, triggering capacity market notices to be delivered ahead of time, where the contracted assets are called upon to prepare their assets for dispatch. The more reliable an asset, and the greater the duration over which the asset can provide power to the grid during a stress event, and the smaller the degree of ‘derating’. Shorter duration, less reliable assets are more severely derated, reducing the level of remuneration received by the asset under its capacity contract. BESS, limited by duration and state of charge, are therefore more severely derated than traditional thermal assets, which are more able to continuously dispatch relatively reliably.

Aggregating across the European capacity markets, Aurora (2025c) estimates thermal generators to have made up at least 71% of total remuneration thus far, with gas alone (mainly, in GB and Italy) accounting for around 50% of total payments. As illustrated in Figure 19, this distribution of payments has been relatively consistent across the six capacity markets; at least two thirds of payments have been awarded to thermal assets within each market, with gas being the single largest asset type contracted in all but the French market, in which nuclear is dominant.

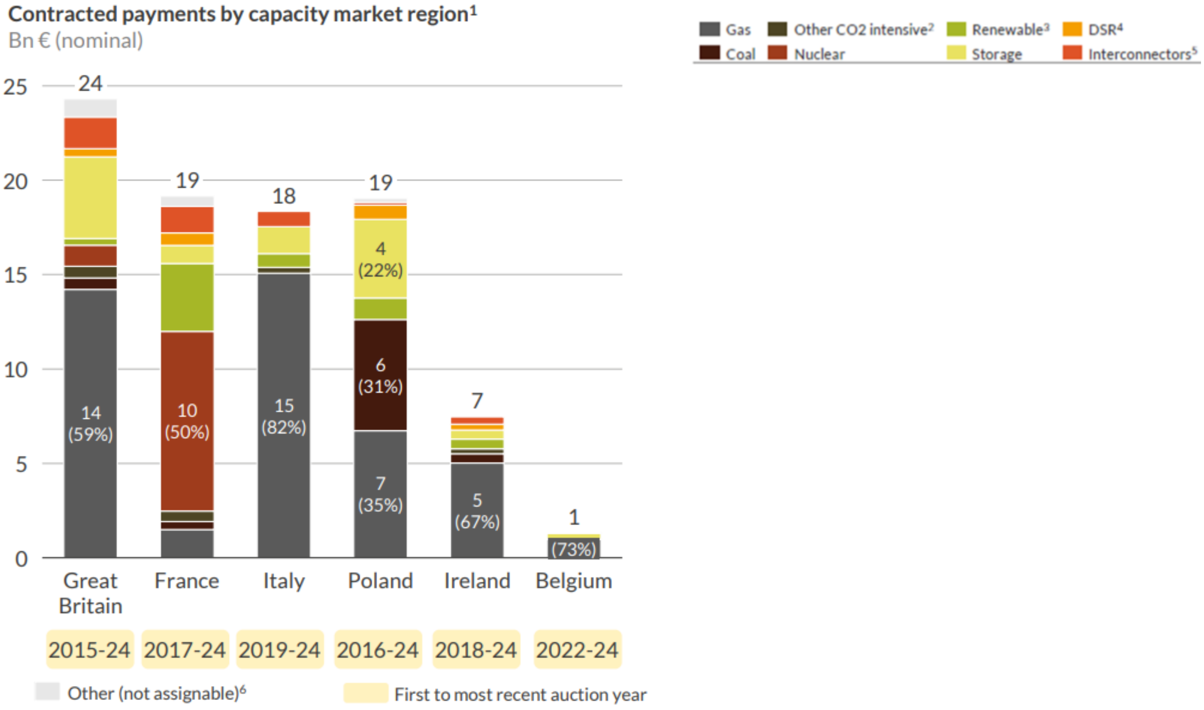


Figure 19: Contracted payments in each of the six European capacity markets, disaggregated by asset type. Note: Years of capacity market operation are displayed below the relevant bar charts. Source: Aurora (2025c).

3.5.3 Capacity market success for BESS

Numerous European gas plants will remain supported by capacity markets well into the 2040s due to the length of contracts already awarded. Nevertheless, as we approach key decarbonisation milestones, the number of new gas and other fossil fuel-based assets should decline, leaving a greater portion of the total capacity target at auction available for low carbon assets, such as new build BESS. In some contexts, European climate targets are encouraging explicit changes to the regulation of capacity markets. While Poland has historically awarded 31% of its contracted payments to coal, the greatest share of all the European capacity market payments awarded to coal, it is now excluded from auction (Aurora, 2021).

There may well also be scope for explicit capacity market reform in other countries to reduce support received by polluting assets and/or increase support for low carbon alternatives, for example incorporating emission limits, creating separate auctions based on carbon intensity or alternatively including minima for low carbon capacity procured. All of the above are reforms currently under consideration in Great Britain's 'Review of Electricity Market Arrangements' (DESNZ, 2024).

Although de-rating factors have hindered BESS competitiveness as compared with thermal assets, by November 2024, almost 25 GW of BESS had been awarded contracts across the six European capacity markets (Aurora, 2024). BESS is clearly gaining traction in capacity markets, as is demonstrated by recent success stories. The Polish have now allocated 22% of total contracted payments to storage, the largest share of any European capacity market, particularly driven by the two latest auction rounds in which BESS were awarded the majority of long-term contracts (Aurora, 2025c). The Polish capacity market has been described as the 'bedrock of the business case' for grid-scale storage, awarding sufficiently high clearing prices to cover a large portion of required returns to break even, significantly increasing the bankability of projects (Aurora, 2021; Energy Storage News, 2024a). The Italian capacity market is also helping to bring forwards further BESS investment, having awarded over 95% of total derated capacity to BESS assets in the most recent auction (Timera Energy, 2025).

3.5.4 Variation in de-rating factor

Derating factors are not consistent across Europe, as shown in Figure 20, even between projects of equivalent duration; countries are able to apply their own unique methodologies.

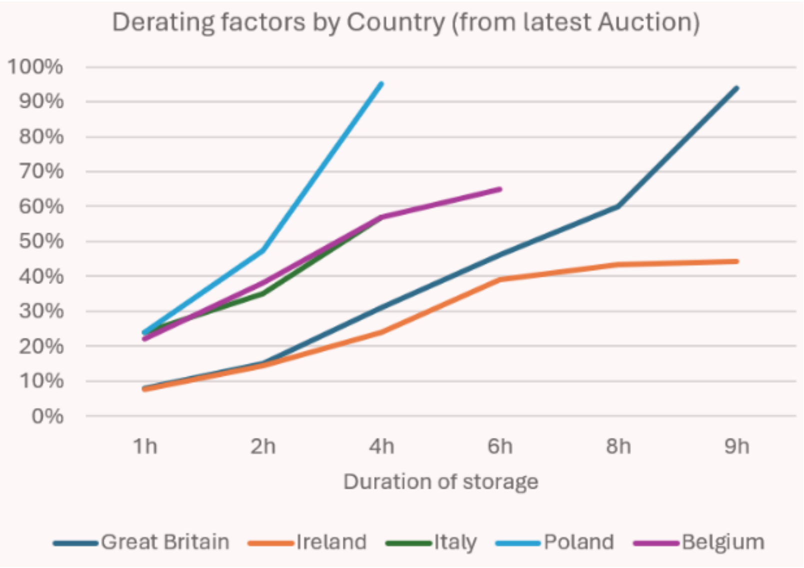


Figure 20: Derating factors by BESS duration and by country in the latest capacity market auction. Source: Müller et al., (2024). Note: a high 'derating factor' in this Figure in fact means a higher rating for reliability – i.e. less derating relative to 100% capacity. Thus, in recent Polish auctions, 4-hour storage counted as being 95% reliably able to meet demand if and when called upon.

However, analysis by Aurora (2024), presented in Figure 21, suggests that at present, the impact of varying de-rating methodology on total BESS revenues is somewhat limited. The figure compares recent clearing prices in each European capacity market, in €/kW, with the prices after the various derating factors have been applied for BESS of 1-, 2- and 4-hour durations. It appears that the capacity markets in which BESS is more severely derated, such as Great Britain and Ireland, also see higher clearing prices. The result being that 'de-rated capacity market value' for BESS of equivalent duration seem to be converging, excluding the French decentralised capacity market.

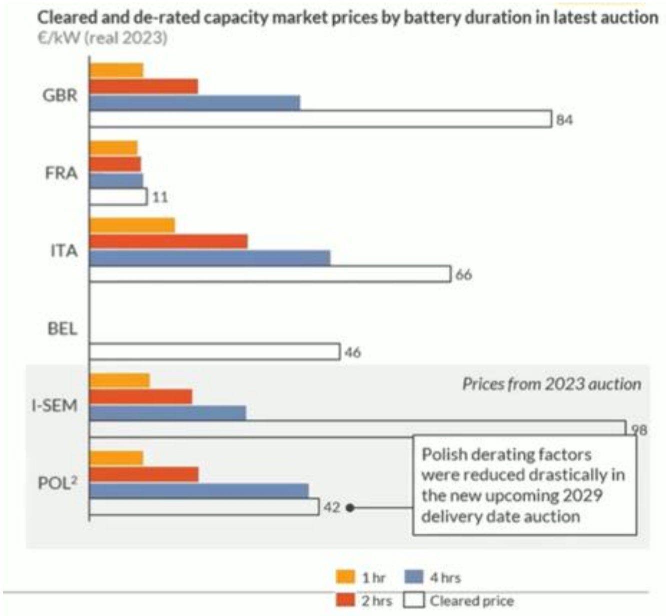
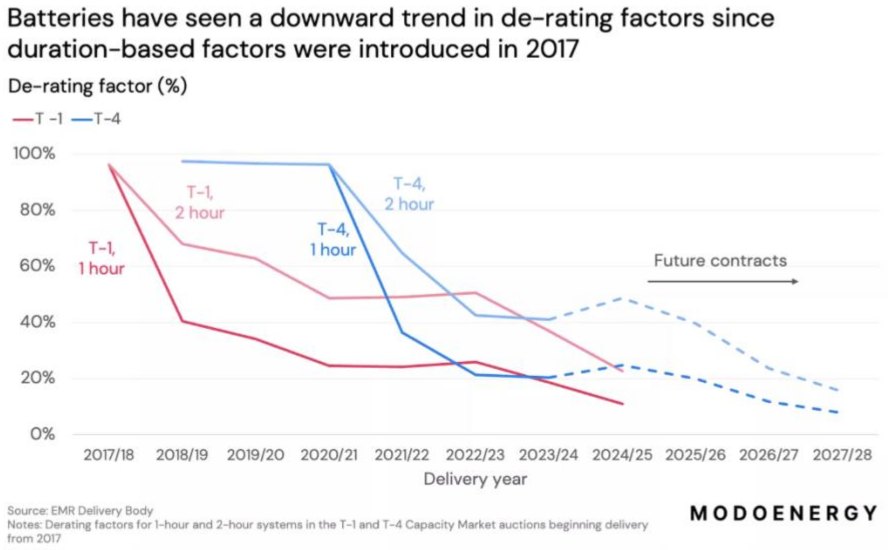


Figure 21: Clearing prices and de-rated prices for 1-, 2- and 4-hour BESS in European capacity markets. Source: Aurora (2024)

While variations in de-rating factor methodology between European capacity markets are currently mitigated by differences in clearing price, system operators may change their methodologies year to year, particularly as the characteristics of low carbon technologies evolve. In some instances, this could be positive for BESS. For example, the methodology used in Great Britain was revised ahead of the 2024/2025 capacity auction, with derating factors for BESS of all durations rising (i.e. reducing the degree of derating, increasing revenue per MW). Though the general trend has overwhelmingly been a reduction in derating factor, which is forecast to continue, as illustrated for the British capacity market in Figure 22.


Batteries have seen a downward trend in de-rating factors since duration-based factors were introduced in 2017

Source: EMR Delivery Body
Notes: Derating factors for 1-hour and 2-hour systems in the T-1 and T-4 Capacity Market auctions beginning delivery from 2017

Figure 22: Historical and forecast derating factor evolution in the Great British capacity market for new and existing asset auctions. Source: Modo Energy (2024b).

As with the other core revenue streams, additional factors will need to be considered looking forwards.

3.5.5 Methodological illustration: charting factors impacting capacity market revenues using systems mapping

The system map presented below reflects factors predominantly impacting 'centralised' capacity markets, a design adopted by all the European capacity markets to date other than the French. Whilst the precise dynamics in each capacity market will be highly dependent on the more granular design choices taken, this map presents some high-level factors to consider when evaluating the outlook for capacity market revenues.

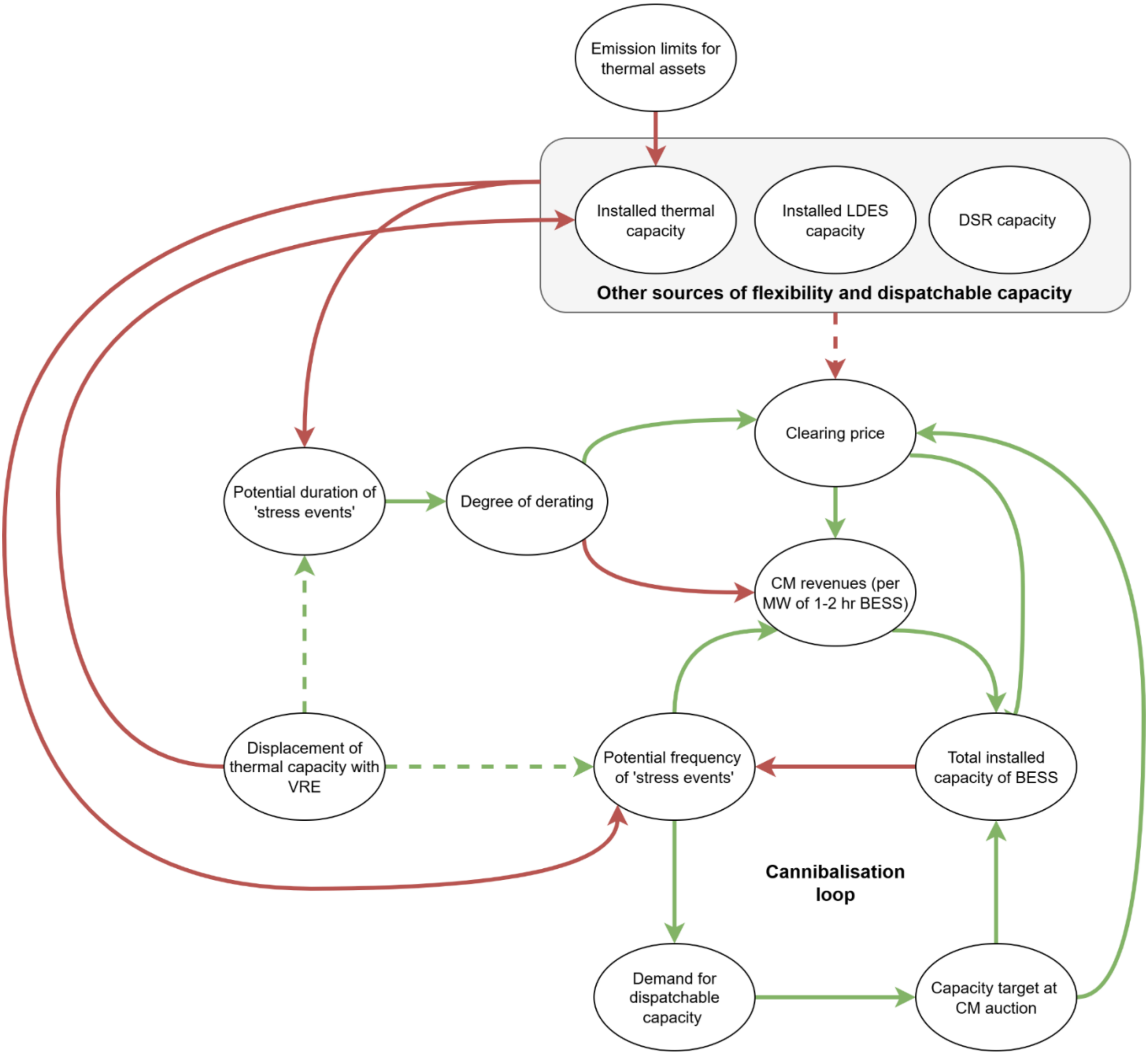


Figure 23: System map illustrating the 'factors' impacting BESS capacity market revenues. The factors are variables, represented by the nodes, and may be impacted by future decarbonisation scenarios and electricity market reforms at the European level, and within each TSO. Interactions between the factors are depicted by arrows. Positive interactions (green arrows) represent variables moving in the same direction, i.e. if one variable were to increase, the connected variable would also increase. Negative interactions (red arrows) represent variables moving in opposite directions, i.e. if one variable were to increase, the other would decrease. Dashed arrows represent interactions that are either weak or conditional. Black arrows represent interactions that may be both positive or negative, or that remain uncertain. For more detailed explanation of system mapping, please refer to Section 0, the Annex 2: The participatory system mapping approach.

The displacement of thermal generation with renewables. Decarbonising power systems should increasingly see the **displacement of thermal capacity (particularly fossil fuel-based generation) by VRE** sources. This switch should increase the **potential frequency of stress events,** and the **potential duration of stress events**, as a greater proportion of our generation is dependent on changeable weather conditions. Balancing the variability of renewables, however, an increase in the deployment of **sources of flexibility and dispatchable capacity** could help to reduce the potential duration and frequency of stress events. Low carbon sources of flexibility and dispatchable capacity include LDES and DSR.

The future of derating factors and clearing prices. For a BESS of e.g.1-2hr duration, should the potential duration of stress events increase, the **degree of derating** will become more severe, thereby reducing **capacity market revenues**[14]. That said, more severe derating factors can lead to higher **clearing prices** as assets bid up to compensate. Additional research would be required to understand the degree to which increases in clearing price are likely to compensate for more severe derating going forwards. Further, the deployment of **other sources of flexibility and dispatchable capacity** should also introduce greater competition to capacity market auctions, ultimately bringing down clearing prices. Should clearing prices decrease, the chance of success for new build BESS assets at auction would likely decrease, as would **total capacity market revenues** for any assets, leading to lower deployment and lower **total installed capacity of BESS**.

However, with an increase in the potential frequency of stress events as thermal assets are replaced by VRE, the **demand for dispatchable capacity** will increase, likely resulting in greater **capacity targets at auction**. This would effectively increase market depth, and therefore increase clearing prices, generating greater BESS revenues and likelihood of success at auction.

The cannibalisation loop. The capacity market exhibits a similar cannibalisation loop to each of the other three system maps. The greater the deployment of BESS and other sources of dispatchable capacity, perhaps due to success at capacity market auction, the lower the potential frequency of stress events, reducing demand for additional dispatchable capacity. This is likely to reduce the capacity target at subsequent auctions, leading to lower revenue potential and likelihood of success, which will likely reduce the deployment and total installed capacity of BESS.

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[14] The impact of more severe derating, due to an increase in the duration of stress event, will likely be more acute the shorter the BESS duration. Longer duration BESS will likely be more resilient to this variable.

3.5.6 Summary: emerging trends and outlook for capacity markets

1) Where available, capacity markets provide a stable revenue stream for utility-scale BESS, reducing revenue risks for investors. The adoption of capacity markets in Europe is set to grow beyond the current six countries, with eight further countries currently considering adoption (see footnote 12).
2) Whilst thermal generation has to date been the main beneficiary of capacity markets, this trend is changing particularly for new capacity. The amount of BESS awarded capacity market contracts is has been meaningfully increasing.
3) As the potential duration and frequency of 'stress events' increases (with the closure of thermal power plants, and an increase in VRE deployment) the minimum required dispatchable capacity on the energy system may rise. Hence, capacity targets at auction may increase.
4) As the rate of new fossil fuel assets coming online slows, the opportunity for low carbon dispatchable assets, such as BESS, to successfully secure both longer- and shorter-term capacity market contracts will likely to rise.
5) Whilst BESS is currently one of the most competitive low carbon sources of storage, new and innovative forms of LDES may enter the market, ultimately increasing competition for capacity market contracts and depressing clearing prices.
6) Relative to current levels, income from capacity markets for BESS of shorter duration (e.g. 1-2hr) will likely decrease. As renewables become the backbone of generation and stress event duration and frequency rises, increasingly severe derating factors will be applied. BESS of longer duration will be able to accrue greater revenues from this stream.
7) Systems reliant more so on wind than solar are likely to experience stress events of greater duration, potentially further exacerbating the degree to which shorter duration BESS assets are derated compared with storage of longer duration.

4 Spain, Italy and The Netherlands: member state case studies

This section presents three short case studies, which together demonstrate the importance of a positive regulatory environment to facilitate BESS investment. The Spanish case study highlights the fundamentals: market access and the legal ability to stack revenues to bring forward the necessary storage to balance a system with high renewable penetration. Italy, with a more positive regulatory environment, provides BESS numerous routes to market and highlights the benefits of a capacity market, alongside other innovative support schemes encouraging a range of investors with different riskappetites to contribute to the country's BESS deployment targets. Finally, the Netherlands serves as an important reminder that unfavourable cost-related regulation can harm the business case as much as factors limiting routes to market.

4.1 Spain: Regulatory Barriers Hamper BESS Deployment

Spain currently has around 85 GW of VRE capacity, and renewables provide 57% of annual electricity (Red Electrica, 2025). Around half this VRE capacity is solar PV (Solar Power Europe, 2025b), yet Spain's BESS capacity (60 MW of utility-scale and minimal behind-the-meter) is far lower than other regions with this level of solar deployment (Joint Research Centre (JRC), 2025; Solar Power Europe, 2025a).

Investing in BESS has not been a regulatory priority in Spain as the country has 1 GW of thermal storage and around 6.5 GW of PSH (Hutters, 2025b). While this capacity may have, until recently, been sufficient, as system variability has increased, so has the need for flexibility. Spain's latest National Energy and Climate Plan (NECP) targets 22.5 GW of storage by 2030, with over 9 GW of BESS (Directorate-General for Communication, 2024).[15]

Given that Spain will likely need BESS's flexibility, at least in the short term, why has deployment thus far been so low? Regulatory barriers limiting market access (as explored in the table below) are the primary explanation.

Table 2: Comparison of Markets Open to BESS in Spain

Market	Current Status	Expected Evolution
Energy Balancing & Ancillary Services	BESS can participate in energy balancing (Hutters, 2025b). Many ancillary services (like FCR) are mandatorily procured from generators, effectively blocking BESS participation.	Spain is expected to create markets for ancillary services *alongside* mandatory generator procurement (Hutters, 2025b). Spain's participation in EU-wide frequency procurement services like MARI will also require BESS be given broader market access, but this will take several years.
Capacity Market	Spain has no capacity market (Directorate-General for Communication, 2024).	Public consultations on a capacity market for existing and newly-built capacity are underway (PacificGreen, 2024). Thermal generators cannot

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[15] There is conflicting data about the specific amount of BESS targeted. The NECP states it aims to have 12.5 GW of short-term storage (like the type provided by BESS), but various sources have interpreted this to mean anywhere between 9-12.5 GW of BESS capacity depending on their expectations what other forms of storage could meet this short-term requirement.

		participate as new-build assets, increasing BESS's competitiveness. The mechanism has been delayed after an initial expected launch in 2024 (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025).
Wholesale Market (Arbitrage)	Despite significant solar deployment, Spain has only moderate energy spreads. These have not been high enough to justify installing BESS for arbitrage (Hutters, 2025b).	In 2024, Spain experienced negative electricity prices for the first time, driven by an oversupply of VRE and insufficient storage capacity (Aurora Energy Research, 2025a). The number of negative price hours is expected to increase, which should create more arbitrage opportunities.

According to SolarPower Europe (2022), revenue stacking is not allowed, thus even if BESS were viable through a combination of balancing and arbitrage, such dual operation is not permitted.

As a result of the anticipated regulatory changes explored in

Table 2, the utility-scale BESS pipeline has grown to 2.4 GW, a useful start towards the 2030 target of at least 9GW (Joint Research Centre (JRC), 2025). Much of the BESS capacity expected to be deployed by 2030, however, will not be funded purely by the market (Renews, 2025). Nearly all of the existing pipeline has received government support, and Spain just earmarked a further €179 million to build utility-scale BESS using EU funds (Sanchez Molina, 2025).

Unlike many European countries where hydropower capacity has already reached its natural capacity limit, Spain is still building new PSH projects with 2 GW announced in 2024 (Directorate-General for Communication, 2024). Behind-the-meter and co-located BESS has received greater regulatory attention thus far than utility-scale, so it is possible that the former two will see greater investment than the latter.[16] Some have suggested that Spain's ambitions on green hydrogen could, in time, reduce the need for BESS (Climate Change Laws of the World, 2021).

Until the Spanish blackout in April 2025, the prevailing assumption was that Spain's PSH and thermal storage capacities would prove sufficient to match the growing variability of generation (Malik and Farhat, 2025). While Spain had begun to make tentative moves to increase BESS bankability, other forms of storage received far more attention. The blackout illustrated that not all forms of storage are created equal; depending on how it

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[16] For more detail on behind-the-meter and co-located BESS deployment, see the briefing paper on this subject.

is configured, BESS can provide black start, a service that PSH cannot (Schmidt and Staffell, 2023). This capability would have been particularly useful to restore power, so it is possible that the regulator will adjust its attitude towards BESS, especially in light of Spain's intention to phase out its nuclear generation by 2035 and given the country's limited interconnection (Jack, Griera and Gavin, 2025; Hutters and Ruiz, 2025). The full response remains to be seen.

4.2 Italy: Capacity Mechanisms Enable BESS Profitability

Italy has 75 GW of VRE capacity (around half of which is solar), with renewables providing 41% of electricity in 2024 (Terna, 2024). In contrast to Spain, Italy has 1 GW of installed utility-scale BESS capacity (Joint Research Centre (JRC), 2025), alongside one of the largest behind-the-meter BESS fleets in Europe (Solar Power Europe, 2025a). This single gigawatt suggests a rather bleak Italian BESS market, but an additional 3.2 GW have already been contracted to come online within the next three years (Joint Research Centre (JRC), 2025). Italy aims to have 11 GW of utility-scale BESS by 2030.

Table 3: Comparison of Markets Open to BESS in Italy

Market	Current Status	Expected Evolution
Energy Balancing & Ancillary Services	BESS can participate in energy balancing. BESS can provide ancillary services that are procured through markets (including for congestion management, primary, secondary and tertiary reserves) (Gore Street Capital, 2025).	While FCR is currently only mandatorily procured from generators, a parallel market-based procurement is expected to be introduced (Hutters, 2025a).[17]
Capacity Market	BESS is able to participate in the CM and is highly competitive (Timera Energy, 2025).	BESS will also be able to participate in a newly introduced, innovative capacity scheme called MACSE, detailed below.
Wholesale Market (Arbitrage)	Italy experiences similar price spreads to Spain, partly because regulatory design does not enable negative prices (Hutters, 2025a). Thermal assets are designated as must-run and resultantly prices oscillate between those set by thermal assets (most of the time)	The potential to bid negative prices into the wholesale market is expected to be added, which could create considerable spreads (Hutters, 2025a). A recent shift to 15-minute settlement periods in day-ahead markets (down from 1 hour) will better enable BESS to

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[17] These reforms are part of a broader set of changes to the Italian market (called TIDE) currently underway and expected to be completed by 2029 (Harreman, 2024).

	and zero. These spreads have not been sufficient to justify investment based on arbitrage (Zakeri *et al.*, 2023; Harreman, 2024).	capture these spreads when they occur.[2]

While Table 3 illustrates a broadly positive regulatory environment, auctions have proven the decisive factor for deploying utility-scale BESS in Italy (Hutters, 2025a). Italy's first BESS capacity was procured through a pilot auction for new FRR capacity. This pilot mirrored a capacity market, providing set compensation while still enabling successful bidders to participate in a range of markets. Italy's remaining BESS capacity has been enabled by its capacity market (open to BESS since 2022). New-build capacity can receive 15-year support, and BESS dominates these auctions with 95% of capacity in the latest new-build auction being awarded to BESS (Timera Energy, 2025).

Developers are expected to face an increasing trade-off between the existing capacity market and the newly-launched Energy Storage Capacity Procurement Mechanism (MACSE) scheme (Cerreto, 2024). MACSE, designed specifically for storage, will provide 15-year fixed contracts for projects of a 6–8-hour duration. PSH projects will be eligible for 30-year contracts (Timera Energy, 2024b). Storage developers can either choose to bid a portion of their total capacity into MACSE (leaving the rest to operate in the market(s) of their choice), or they can assign all their capacity to MACSE. In the latter structure, batteries will still operate in other markets most of the time, but developers can only keep 20% of total profits.

While the first MACSE auction should be held in the third quarter of 2025, this scheme is intended to bring 10 GWh of BESS to the market by 2028 (Timera Energy, 2025). Assuming a duration between 6-8 hours, this would correspond to 1.25-1.5 GW of utility-scale, mid-duration BESS. While MACSE auctions are expected to attract fierce competition, this market design is likely to appeal to risk-averse developers willing to trade the ability to generate unrestricted profits for revenue stability. Developers who believe they can generate more upside from market participation (despite the inherent volatility of this approach) will likely continue participating in the traditional capacity market.

Though the Italian system is not completely comparable to other EU power systems, as it uses zonal pricing (with seven distinct zones) (Hutters, 2025a). This design was implemented partly because most interconnection, PSH, and industry are centred in the north, while generation is concentrated in northern and central Italy. Most solar, however, will be deployed in the south, necessitating greater cross-zonal transmission capacity and southern storage. Consequently, the first MACSE auction will have minimum procurement targets for southern zones to ensure sufficient flexibility (Timera Energy, 2024c).

In contrast to Spain, Italy demonstrates the level of BESS deployment that can be achieved when government policy aims to reward a full range of services that BESS can provide, and/or mitigate developer risk. Both Aurora Energy Research and Rabobank state that fully merchant projects are still unviable in Italy due to low profitability (Cerreto, 2024; Hutters, 2025a). With the simple addition of a capacity market, Italy is well on its way to meeting its 2030 BESS deployment target.

4.3 The Netherlands: Grid Connection Fees Impede BESS

In the Netherlands, BESS has broad market access, providing services like FCR, mFRR, and balancing (TenneT, 2024). While there is no capacity market, Dutch batteries can profit from arbitrage in the wholesale market. Yet, the country currently has only 0.2 GW of installed utility-scale BESS capacity (Joint Research Centre (JRC), 2025). The Dutch transmission system operator, TenneT, is targeting over 5 GW of BESS by 2030, but modelling results indicate the market will not bring forward this much storage.

High grid fees (which are paid exclusively by off-takers, including utility-scale BESS when charging) broadly explain this low deployment (Scrimshire and Savenije, 2024). Such grid fees are not unusual, but as the Dutch system has decarbonised, it has become incredibly constrained. Consequently, grid fees have risen, quadrupling in a single year, to the point where these fees now represent between 20-50% of the revenue a BESS project could earn annually (Timera Energy, 2024d).

Recognising the barrier posed by high grid fees, TenneT recently announced two reforms for transmission-connected BESS (Scrimshire and Savenije, 2024). The first being dynamic grid fees, varying based on the amount of grid congestion at the time of charging. The second is a non-firm grid connection whereby TenneT can remove a BESS's grid access for 15% of the time in exchange for reducing all the battery's grid fees by 50%. These combined reforms are expected to reduce grid fees for BESS by 65-75% from their current levels (Broess, 2024).

The risk of these reforms is that if the 15% period occurs when BESS would ideally export, the loss in revenue could offset the reduced fees. Distribution system operators have, however, also begun to implement similar reforms (Timera Energy, 2024d). While these regulatory changes could improve the investment case for utility-scale BESS, co-located projects might still prove more investable than utility-scale as these projects avoid grid fees by charging behind the meter.

The Dutch case illustrates that even when BESS has broad market access, regulatory design can severely restrict deployment. BESS projects in countries like Germany and Belgium (which are either exempted from or pay reduced grid fees) are likely to be deemed more bankable (Aurora Energy Research, 2025b).

5 Conclusions: emerging and future trends and key recommendations

Our first (Part 1) report to EIB, on the *economic appraisal* of utility-scale BESS, investigated the holistic economic benefits of further investment in BESS across Europe. This second report, on the *financial appraisal* of utility-scale BESS, has evaluated the state of play for prospective investments.

5.1 Summary of emerging and future trends

BESS costs have rapidly declined, consistently surpassing expectations, especially in recent years. The sharp decline in costs has been an important contributing factor to the acceleration of utility-scale BESS deployment in Europe. Further cost reductions are forecast, subject to the ability of critical minerals supply chains to keep pace with rising demand across numerous expanding sectors. Most BESS costs are upfront capital expenses, therefore less uncertain upon the financial appraisal of a prospective project.

The report then identified three main categories of revenue streams, with varied characteristics. In regions where BESS deployment is in its infancy, but crucially where the technology *has* access to ***the ancillary services***, frequency response revenues can be notably high. While lucrative, this revenue stream is likely to be fleeting. Indeed the ancillary services, particularly frequency response, are inherently shallow, creating high risk of price cannibalisation with relatively little BESS deployed. Ancillary services procuring energy to resolve larger imbalances and manage network congestion are typically a little deeper and may therefore be more resilient to saturation until a greater capacity of BESS is operational. There is likely to be a modest increase in the demand for ancillary services as renewables displace thermal generation, however the market depth will ultimately not match the growing demand for energy shifting (arbitrage) in wholesale markets. Eventual saturation of most ancillary service markets seems likely. Hence, a business case predominantly based on the promise of high ancillary service revenues carries high risk.

The second revenue stream, ***energy arbitrage***, has grown in significance in recent years. Price spreads, across which arbitrage can be conducted to generate revenue, tend to grow as renewables deployment begins to accelerate; low-cost VRE increasingly drives low and negative prices during periods where their output can meet demand. The markets observing the greatest price spreads tend to have strong VRE deployment, particularly in solar due to its anticorrelation with demand, but critically also remain reliant on fossil fuel-based generation to set wholesale prices for a significant proportion of time. In said markets, the high fossil fuel commodity costs of recent years have contributed to the rise in price spreads. The most lucrative markets for arbitrage also typically have little storage and flexibility, which could otherwise help to balance the system at lower cost, cannibalising potential price spreads. In regions meeting the aforementioned conditions, arbitrage is likely to be the dominant revenue stream going forwards, particularly as the ancillary services saturate. However, in the vast majority of contexts, price spreads in wholesale markets are not (a) sufficient, or (b) stable enough to create a robust business case. Further, arbitrage is subject to numerous medium to long term uncertainties which could erode future revenues, including but far from limited to the future of fossil fuel commodity costs and the bidding behaviour of various types of storage, and their potential to flatten price curves.

The final revenue stream, ***capacity markets***, are only available in six European countries, although are under active consideration in eight further member states. For new build assets, capacity markets provide a stable source of revenue for the duration of long-term contracts won at auction. While thermal assets have historically received the most support from capacity markets, BESS assets are proving increasingly competitive. Relatively severe de-rating factors are applied to BESS of shorter duration, reducing the scale of revenues possible under this stream. As thermal assets are gradually phased out of European energy systems, the number of capacity market contracts available for low carbon storage like BESS should rise, but increasingly severe de-rating factors are likely to be applied as the potential duration of stress events increases. Henceforth, for the time being, capacity markets present a valuable additional source of revenue to both boost and stabilise the investment case, but in the longer term they may become less important in their share of total revenues depending on the evolution of de-rating factors.

5.2 A checklist: improving the financial outlook and reducing the vulnerability of BESS revenues

Derived from the findings of this report, we present an overarching checklist of considerations to improve the financial outlook and de-risk a prospective BESS project:

1) Seek to invest in regions allowing BESS access to market across the full suite of revenue streams, and regions explicitly permitting the stacking of revenues. The diversification and stacking of different revenues reduces risk, particularly viewed over time. Please see Annex 1: Further information on revenue stacking.

2) Regions with digitalised system operations and low skip rates (Section 3.3.6.2) are also key to ensure that BESS can, in practise, operate efficiently across numerous revenue streams (EY, 2024).

3) Identify regions either already exhibiting the key factors creating large price spreads, or in regions where future energy scenarios suggest a transition that will create volatility in wholesale markets.

4) Seek to invest in regions with capacity markets and/or other innovative schemes (such as MACSE, depending on desired rate of return) which provide a degree of revenue certainty.

5) Careful consideration of BESS characteristics, ensuring that assets have the operational flexibility to optimise across numerous routes to market. Smaller batteries of shorter duration may initially give the best return on investment in regions with currently lucrative frequency response markets. However, as the ancillary services inevitably saturate, these batteries are unlikely to be as competitive when conducting arbitrage in wholesale markets, or in capacity markets due to de-rating. Batteries of greater nameplate capacity and of longer duration are likely to be favourable for maximising revenues in the longer term. Recognition of this, or perhaps forward-looking plans to augment, are indicators of a well-informed business case.

6) Given the location dependent nature of higher renewables systems, consider the precise location of the BESS asset within a particular region with respect to grid constraints. There may be lucrative markets for the remuneration of congestion management, but grid fees may also vary significantly depending on asset location within the network. Potential reforms to sharpen locational signals should be carefully monitored as they would likely impact BESS revenues.

5.3 Methodological recommendations for the financial appraisal of utility-scale BESS projects

European BESS projects operate in evolving markets and regulatory environments. With increasing acknowledgement of the fundamental need for greater sources of storage and flexibility to balance energy systems with rising VRE penetration, regulatory environments currently not supporting BESS deployment *should* improve. Overt barriers to investment should gradually be tackled, such as high grid fees and the lack of remuneration for essential system services.

That said, this report has also illustrated the sheer number of variables at play across the core markets in which BESS accrues revenue. These markets will likely be subject to significant change as European energy systems transform. Our primary recommendation to the EIB is therefore to take a *dynamic* approach to the financial appraisal of utility-scale BESS projects. The cannibalisation of prices in shallow revenue streams which typically start as the most profitable in regions with little BESS deployment can radically change the revenue outlook of an investment within the space of a single year. The back-testing of revenues is therefore not suitable to evidence the financial viability of a prospective project.

Energy system models may be used to project electricity prices and generate BESS revenue forecasts. Models must use *appropriate* assumptions and simplifications to adequately represent the likely dynamics expected of electricity markets going forwards. We have outlined the drivers likely to affect storage economics, identified using system maps. We recommend that system mapping is used to critically assess inputs and outputs where modelling is used to project BESS revenues.

1) Given the pace of change currently observed within electricity market trends and the policy landscape, we recommend that the EIB monitors the variables identified within the system maps, as well as specific regulation in key regions of interest.
2) The variables and dynamics identified within each map should be appropriately represented within the models used to project revenues (as *inputs and assumptions*).
3) The system maps, used alongside country-specific future energy scenarios, may be used to assess whether variables are likely to increase or decrease, and on what time horizon, against which model *outputs* may be compared.
4) The system maps have shown that modelling prices without assuming structural changes to the system is likely to yield poor results.
5) Should the EIB conduct system mapping exercises internally, or with external experts, to pick up new variables and dynamics, or to produce country specific maps for regions of particular interest.

Annex 1: Further information on revenue stacking

One of our core conclusions is to prioritise investment in regions in which BESS has access to numerous markets, and in which the regulatory framework explicitly allows the stacking of revenues across streams. This conclusion arises from the fact that the ancillary services are highly likely to saturate given their shallow nature. This is particularly true for frequency response markets, which often start as the most lucrative, but will likely see very low prices as BESS deployment accelerates. Investing in regions with (a) access to numerous markets rewarding a variety of system services and (b) the legal ability to stack revenues, adds the possibility of a more flexible operational strategy and helps to mitigate this impending revenue risk, ultimately increasing the robustness of the BESS business case.

While revenue stacking can start by boosting revenues in regions with little existing BESS deployment, once the core ancillary services have saturated, stacking across the remaining markets is likely to become increasingly important simply to retain project viability. These markets are likely to include arbitrage, capacity markets, other innovative longer-term contracts, as well as the remaining unsaturated or new ancillary services.

There are three types of revenue stacking (NESO, 2025).

- ***Co-delivery.*** An asset receives numerous payments for selling the *same capacity*, at the *same time*, in the *same direction*. For example, receiving revenue from the capacity market and any ancillary service simultaneously. This type of splitting is currently under review in GB.
- ***Splitting.*** Receiving numerous payments for using *different capacity* from a *single asset*, *at the same time*. This could occur for services 'in the same direction', or for services 'in the opposite direction' e.g. aFRR *capacity* up and aFRR capacity down (assuming bids are not mandatorily symmetric), so long as the two would not be activated simultaneously. Please see slide 130 of NESO (2025) for an matrix of permitted asset 'splitting' conducted for the GB context. Equivalent information should be acquired from TSOs in regions of interest.
- ***Jumping.*** An asset receives numerous payments for services in different times. Examples are widespread, but technological parameters should be considered if planning to 'jump' revenue streams in adjacent time blocks.

Ultimately, it is the job of an optimiser to determine the most lucrative routes to market in real time, considering the types of revenue stacking permitted in the relevant jurisdiction. As discussed in Section 2.1, optimisers will typically negotiate a cut of total revenues between 5 and 10%.

The capacity market and revenue stacking. An asset is only required to reserve its contracted capacity if a capacity market notice has been issued, indicating a potential system stress event. Notices are typically issued hours in advance of required delivery.[18] If the asset cannot deliver its contracted capacity when called upon, penalty charges must be paid. It is true that capacity market notices are issued during potential hours of system stress which are likely to be characterised by higher wholesale prices. However, capacity market notice activation is ultimately relatively infrequent, meaning that the trade-off between revenue accrual from a capacity market contract versus other streams is relatively small; capacity markets broadly allow assets to participate in other markets freely whilst accruing a stable source of income.

Temporal correlation of high prices across markets and the impact on 'jumping'. Before ancillary service saturation, we assume that high prices across the various revenue streams will not necessarily exhibit temporal correlation, meaning 'jumping' would likely benefit total revenues. In Germany, for example, jumping would be lucrative given high arbitrage revenues while the ancillary services, at present, remain unsaturated (Rabobank, 2025c). Once the ancillary services *have* saturated, system mapping identified the ability of opportunity costs to re-inflate prices. However, this is by nature likely to be during times of high potential revenues in other streams, meaning the ability of assets to profit from 'jumping' between the saturated stream and unsaturated will be limited.

Jumping, and other forms of stacking, between the remaining unsaturated revenue streams will be important. In Germany, *new* ancillary services and a capacity market are currently under consideration, and a regulatory environment supporting various types of revenue stacking across these new streams would enable assets to mitigate the risk of frequency response saturation (Rabobank, 2025c).

The importance of 'splitting', particularly in the context of the ancillary services. In frequency response markets (FCR and aFRR, for example), there is often a minimum and maximum capacity that can be offered at tender, particularly for indivisible bids. For example, RTE, the French TSO, prescribes the following rules for FCR capacity procurement: 1MW ≤ proposed power ≤ 25 MW (RTE, 2025). Given that the average capacity of single battery assets currently being deployed in Europe far exceeds these values, if legally permitted, the remaining capacity could be deployed for other services. Whilst there are technical considerations, including the need for the services simultaneously delivered to move in the same direction (e.g. tuning up or down, charging or discharging), it would make economic sense to make full use of the BESS assets

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[18] In GB, capacity market notices are issued four hours before dispatch.

connected to an energy system. The legal ability of assets to execute an operational strategy that includes ‘splitting’ will be determined by individual TSO rules. Please refer to slide 130 of (NESO, 2025) for a matrix presenting permissible ‘splitting’, mapped for the GB context. The Enduring Auction Capability (EAC), implemented in 2023, allows splitting between some of the key frequency response markets in GB (NESO, 2023). Note that splitting is also explicitly permitted across the wholesale market and balancing mechanism.

Annex 2: The participatory system mapping approach

Overview of system mapping process

Part 1) Desk study. Researchers started with a period of 'desk study' in which past and emerging trends across the four most commonly remunerated BESS system services were analysed. This provided a foundation of understanding from which researchers could identify existing/known variables (nodes) and dynamics across the four 'systems' and draw preliminary maps. These maps were not shared with workshop participants.

Part 2) Participatory systems mapping: workshop 1. The first workshop was held in London with electricity market and storage experts, several of whom were academics, and some from industry. The objective of the workshop was for experts to work together to produce one system map for each of the four system services, and in doing so:

a) Determine key factors that could impact future BESS revenues in each system
b) Understand the interactions between the factors, and illustrating them in maps
c) Identify any potential factors requiring further investigation

A small number of 'starting nodes' were provided by the researchers, after which the participants independently built a more complete map with a full set of factors (nodes) and their interactions. Guidance was provided in the form of questions to prompt deeper debate amongst participants and to inject new ideas, but researchers did not themselves participate. For a full practical guide on conducting participatory systems mapping methods, please refer to (Penn and Barbrook-Johnson, 2020).

Part 3) Consolidation and European input: workshop 2. The second workshop was co-hosted in Paris with colleagues at Paris Dauphine University. The objective of this second workshop was to present the system maps to an audience with a range of European storage and electricity market expertise, inviting comments and reflections on the maps produced in the first workshop. Researchers also brought specific questions and sought to understand whether any dynamics in the maps diverged from European experiences. The workshop discussions and feedback were integrated into the system maps and discussion sections of this report.

Reading system maps

The nodes are 'factors' impacting BESS revenues under the relevant stream, expressed as variables. The factors may increase or decrease. Country-level scenarios may inform the likely trajectory of the factors.

The arrows represent causal links between two related nodes. Arrows denote the direction of interaction as well as the nature of the causal influence.

- ***Positive arrows (green):*** Variables move in the same direction. The connected node will increase if the node of origin increases. The connected node will decrease if the node of origin decreases.
- ***Negative arrows (red):*** Variables move in opposite directions. The connected node will decrease if the node of origin increases. The connected node will increase if the node of origin decreases.
- ***Black arrows:*** the interaction between variables could be positive or negative.
- ***Dashed arrows:*** the interaction may be weaker, or conditional on external factors.

The system map below is taken from our report with the EIB and makes for a relatively simple example. This map indicates that an increase in renewables deployment would increase the intermittency of the generation stack (a positive interaction denoted by a solid green arrow). Equally, an increase in system balancing capacity on the energy system would decrease the periods of surplus (a negative interaction denoted by a solid red arrow).

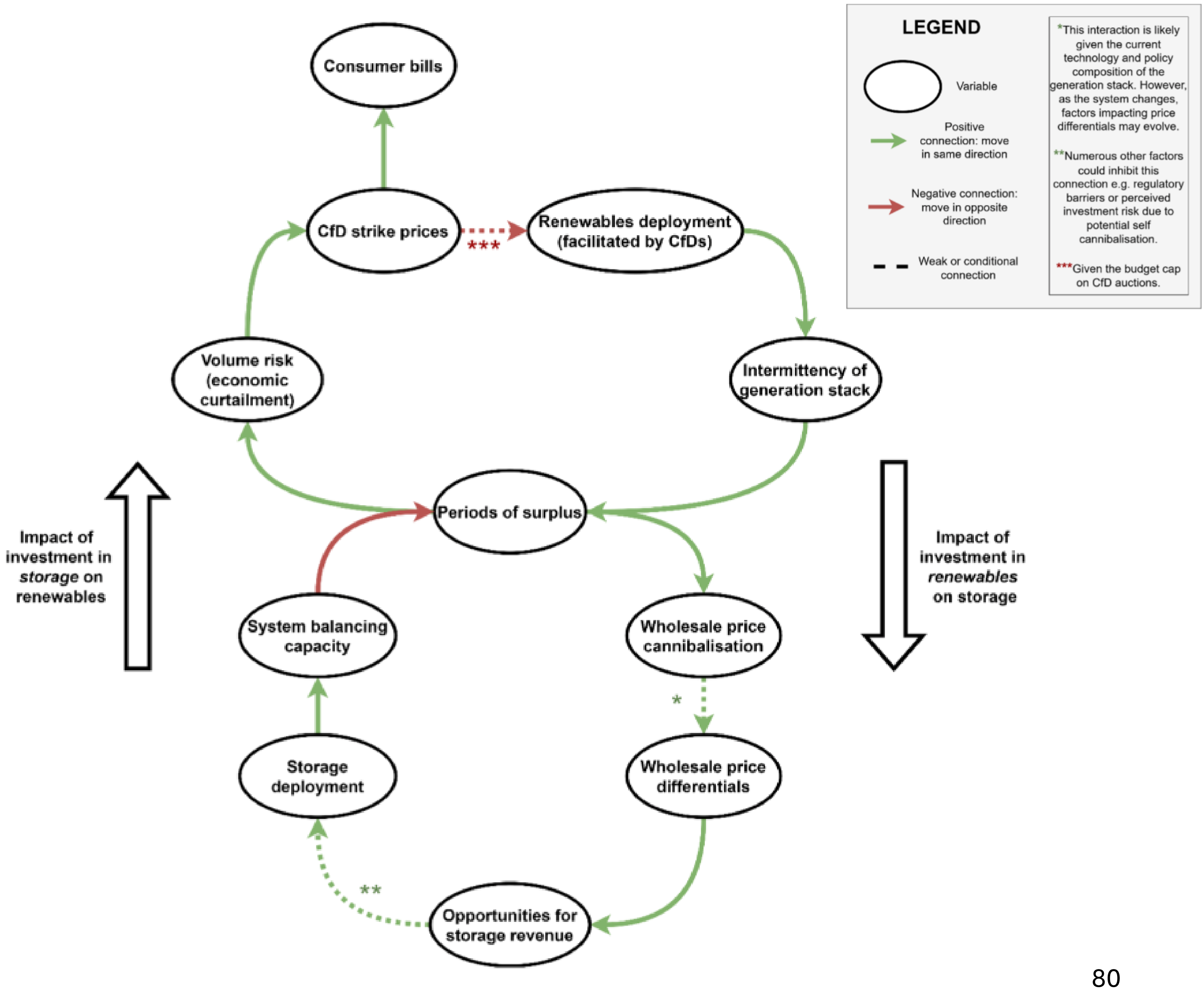

Figure 24: Example system map illustrating simplified dynamics between the deployment of renewables and storage

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