



Briefing Paper on Behind-the-Meter and Co-Located Battery Energy Storage Systems (BESS)

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About this publication

This publication is released as the second of three 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 additional publications on utility-scale BESS, please visit our [website](#).

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Executive Summary

Opportunities for behind-the-meter and co-located BESS

The deployment of battery energy storage systems (BESS) is key to reaching the EU's decarbonisation targets outlined in Fit For 55 and REPowerEU as this technology enables variable renewable energy (VRE) to be shifted across time. Attention in recent years in the storage industry has primarily been on utility-scale storage, but this briefing quantifies the current scale and characteristics of what we deem hybrid storage assets (behind-the meter (BtM) BESS and batteries co-located with VRE).

In 2022, the EU had over 1,000 GW of electricity generation capacity, with over 200 GW each of wind and solar capacity (Eurostat, 2024), compared to an estimated BESS capacity around 25 GW (EASE and LCP Delta, 2025); see also footnote 1. The table below illustrates cumulative installed capacity for Europe, with BtM broken into residential and commercial & industrial (C&I).

Utility-Scale	Residential BtM	C&I BtM	Co-Located BESS and VRE
13	20.5	1.4	1.75

Table 1: European Installed BESS Capacity by Type (in GW) (EASE and LCP Delta, 2025).¹

Challenges

Deployment of hybrid storage assets is incredibly reliant upon each member state's regulatory environment, so these installations are not evenly spread across the EU but are instead clustered primarily in Germany and Italy. BESS profitability is also limited to the daily price spreads in member states. While some countries have quickly adjusted their regulatory frameworks to enable non-utility-scale BESS to participate in all electricity markets, these batteries are still barred from profitable markets in some member states.

Considerations

Hybrid storage assets are just entering the territory of profitability in many member states.

¹ There are currently around 5 GW of utility-scale BESS in the EU (Joint Research Centre (JRC), 2025); Table 1 refers to the European total including significant deployment in UK and Switzerland. Capacities of hybrid storage assets in non-EU countries are likely marginal. Figure for co-located and C&I BESS only includes capacity added from 2020-24 and thus actual figures are potentially slightly higher. Co-located figures only represent BESS co-located with VRE generators. Additionally, many countries have not yet moved to legally define BESS, treating the batteries instead as either generators or consumers (Directorate-General for Energy, 2023). This makes it difficult to track existing BESS deployment unless a member state has explicitly chosen to track BESS (ENTEC, 2023).

- Co-location is still a nascent in the EU but has the potential to become a primary means of developing variable renewable energy (VRE), protecting projects from rising periods of negative electricity prices.
- For C&I BESS, industrial decarbonisation incentives, like those embedded in the Clean Industrial Deal, should accelerate electrification and BESS deployment.
- For residential BtM BESS, a key value stream is likely to be the potential to aggregate many BtM assets together through a virtual power plant (VPP).

EIB relevance

Our research on storage has emphasised that as part of its approach to storage, the EIB needs to understand the wider context of the evolving European system. Alongside dedicated, discrete utility-scale storage projects, hybrid storage assets form part of that wider landscape. They could make a valuable contribution to the EU's goals, and may complement - but also sometimes compete with - direct utility-scale storage projects.

Key distinguishing features compared to dedicated utility-scale storage are that such hybrid storage assets:

- are even more dependent on the specificities of national regulations, beyond explicit storage rules because their financial viability depends on detailed terms of feed-in from distributed generation (for BtM BESS) and the terms of investment support (for VRE generation);
- often are (or could be) bundled in with other energy-related investments, by energy consumers or generators;
- may often involve motivations beyond purely cost and revenues, including a sense of enhanced ownership, control, and security over energy (especially for BtM BESS).

An implication is that the EIB should conduct granular, country-specific regulatory and market assessments of the scale and context for hybrid storage investments and consider a range of options for supporting such investments. These potentially could include recognition of strong socio-environmental/security co-benefits of projects beyond direct financial returns, and screening other energy-related projects for potential to embed hybrid storage.

1. Introduction

As the European Union (EU) progresses in its aim to decarbonise electricity generation, the ability to store low-carbon power is becoming increasingly vital. Battery energy storage systems (BESS) powered by lithium-ion batteries are becoming a key provider of this storage, enabling the usage of low-carbon power regardless of weather patterns.

There are three primary means of deploying BESS: utility-scale; behind-the-meter; and co-located with generators. Utility-scale batteries, which are stand-alone systems connected to the transmission or higher-voltage distribution systems and feed *directly*

into the grid, have received most investor attention. Such batteries often participate in a range of electricity markets and are installed to generate profit for their owners.

This briefing paper complements our reports to the EIB on utility-scale batteries, outlining key data and features of the two other main categories of battery storage. In Europe, the term behind-the-meter (BtM) is often used to describe any form of storage or generation that is not utility-scale (i.e. EASE, 2023). As co-located and BtM BESS have very different commercial and operating characteristics, we will refer to them *collectively as hybrid storage assets*:²

- In this paper, we use BtM to describe only batteries designed to primarily provide direct power to their residential or commercial/industrial (C&I) owners. These batteries are referred to as BtM because they are located behind their owner's energy meter. BtM batteries are often (but not always) combined with small-scale variable renewable energy (VRE) such as rooftop or local PV. While functionally the same, we distinguish between residential (very small scale) BESS, and BESS used by C&I customers due to the differing motivations of these owners.
- Co-location in contrast, refers to storage that is co-located with dedicated, utility-scale VRE generation,³ with the intent to extend and smooth the power sold from the combined site to the electricity grid.

As the electricity system evolves, the balance between BtM, co-located, and utility-scale storage and the roles each of these plays in the system will also evolve. The latter *in theory* has potential to be more efficient from a systems perspective since the BESS is visible to the energy system operator and can be dispatched as needed.⁴ Utility-scale batteries are likely to profit most when sited in constrained areas of the grid, able to charge using inexpensive power that would otherwise be curtailed or dispatch when others are blocked (Bush, 2024). BtM and co-located BESS are less flexible in location; the former will depend on the location of existing households and industries while the latter is linked to the ideal locations for VRE (Apostolopoulou and Poudineh, 2024).

2. Behind-the-Meter BESS

The deployment of residential BtM BESS in the EU began primarily in Germany to prevent mismatches between diurnal solar generation profiles and demand profiles, created by significant BtM solar deployment due to the country's generous 20-year residential solar

² This briefing paper will not address micro-grids or sites that are not connected to the grid. Also, we do not consider vehicle-to-grid technology, which may over time become a significant but quite distinct source of distributed storage. For a brief overview of this nascent use-case for electric vehicles, see European Environment Agency (2022).

³ Co-location of other forms of energy infrastructure (i.e. wind and solar or hydropower and BESS) is also possible but will not be addressed in this report.

⁴ This will depend on the degree to which co-located BESS is in practice blocked from discharging to the grid, but utility-scale batteries in principle could be useful to the grid than when behind-the-meter. In practice this will depend on the specific set-up, but to the extent that BtM BESS is generally not visible to the grid operator and cannot be called upon when needed (unless it is aggregated in a 'virtual power plant') makes it likely to be less useful in providing the range of services utility-scale BESS can.

feed-in-tariffs (FiTs) (Zhu, 2023). To incentivise BtM BESS to smooth solar output, policymakers implemented 20-year FiTs for such consumer-based BESS deployed in conjunction with residential solar in 2013.

EASE and LCP Delta (2025) estimate European BtM capacity to be 22 GW. The pace of residential BtM deployment reached 6.9 GW in 2024, 58% of which was built in Germany, with the remaining majority located in Italy; only a small percentage was deployed in the rest of Europe. Environmental concerns related to climate change (as well as enhanced on-site energy ownership/security) are viewed as a primary incentive for installing BESS, which is often deployed in conjunction with BtM solar (Kaps and Netessine, 2025).

Around 1.4 GW of BtM C&I capacity has been deployed in Europe between 2020-24 (EASE and LCP Delta, 2025), with 0.5 GW added in 2024, located primarily in Germany, Italy, the Netherlands and Sweden. Growing concerns from C&I customers about security of supply and a desire to insulate themselves from price shocks are expected accelerate C&I BESS uptake (SolarPower Europe, 2024b).

BtM batteries are far smaller than utility-scale batteries, as the former primarily back up self-generated solar PV. C&I batteries generally range from 100 kWh to 5 MWh, while residential batteries mostly fall in the 5 kWh to 35 kWh range (Tickler, 2025). BtM BESS durations (at maximum output) are generally one hour or less (SolarPower Europe, 2024b). With declining lithium-ion costs (BloombergNEF, 2025), these batteries have slowly become larger, creating more potential for these batteries to do more than smooth self-generated VRE output.

The simplest means of BtM BESS operation is to charge during a period of low energy tariffs and discharge when tariffs are higher, thus reducing the amount of expensive grid power its owner must purchase (Tickler, 2025). The BESS might charge directly from BtM VRE or from the grid (depending on regulatory design). For the latter, as well as two-way metering, there must be considerable price variations throughout the day to offset BESS installation costs.

In general, the ability for BtM BESS to participate in many energy markets is quite limited, with member states either explicitly or implicitly banning BESS (Agency for the Cooperation of Energy Regulators (ACER), 2023). In some cases, these exclusions exist because system operators view BtM BESS as riskier than utility-scale batteries (Scrimshire and Stephan, 2024); in others, these barriers exist simply because the regulatory regimes have not been updated to reflect the emergence of batteries. For example, in Italy, BtM BESS is barred from exporting to the grid in an attempt to avoid contributing to grid constraints (EASE, 2023).

Arbitrage profits from participation in wholesale markets are expected to form the core value proposition of utility-scale BESS (de Giovanni and Warren, 2024). Yet, some member states, such as Bulgaria, the Netherlands, Poland, Finland, and Norway, have not legally defined roles and responsibilities for distributed energy resources (including BtM BESS (ACER, 2023). This effectively bars BtM BESS from wholesale markets.

The outlook for capacity markets (CMs) is similar. To date, only France, Belgium, Ireland, Italy, and Poland have allowed, or witnessed, distributed energy generation participation in their CMs. Ancillary services markets (and therefore balancing markets) are also often closed to BtM BESS. Only Germany, Estonia, the Netherlands, Romania, and Slovenia have fully opened balancing markets to distributed energy sources.

Virtual power plants (VPPs)⁵, where owners relinquish control of their BESS to an aggregator, allow distributed energy assets to participate in markets like ancillary services (Scrimshire and Ferrell, 2024; Bali, 2025). In Germany, for example, individual BtM BESS cannot discharge to the grid, but BESS in a VPP can provide frequency services (Marra and Kleefeld, 2024). VPPs have emerged in several member states including Germany, France, Italy, Sweden, and Spain, and could prove an important tool for increasing BtM BESS profitability.

One complication of operating VPPs is limited smart meter deployment in some member states. Smart meter deployment in some member states is low (e.g. Germany (<1%), Lithuania (12%), Poland (22%), Belgium (40%)), especially compared to the Nordic countries where deployment is near 100% (Openvolt, 2024). It is not impossible to operate a VPP without a smart meter (as demonstrated by significant deployment in Germany), but reduced data visibility can limit profitability (Sonnen Content Team, 2022).

Commercial and Industrial BtM

Current C&I capacity is concentrated in Germany, Italy, the Netherlands, and Sweden (LCP Delta and EASE, 2025). As the cost of lithium-ion batteries has declined, there has not been a linear relationship between price and size (Tickler, 2025). While utility-scale batteries have become comparatively cheaper, mid-size installations have not seen commensurate price decreases until recently, explaining the somewhat limited deployment (only around 3 GW according to LCP Delta and EASE (2025)).

C&I BtM is often viewed as a lower-carbon alternative to on-site diesel backup (Energy Storage Ireland, 2023). As industries become more dependent upon electricity to meet the EU's decarbonisation targets, on-site electricity backups will become increasingly valuable (LCP Delta and EASE, 2025). One study projects annual capacity additions of C&I BtM BESS should roughly double from 0.5 GW/yr in 2025 to 1 GW/yr by 2030.

C&I customers may choose to install VRE and/or BESS on their own, but they may also choose to outsource some of this risk to a power purchase agreement (PPA) (RE-Source, 2020). The EU's 2024 European Market Design reform includes provisions to encourage member states to reduce PPA barriers, but PPAs are still severely limited in many countries (SolarPower Europe, 2024a).

While growth in C&I batteries is expected, it is difficult to determine whether these batteries are truly profitable on their own. C&I customers will place a certain value simply on knowledge of having backup energy in the case of a grid outage. The metering

⁵ VPPs by definition do not necessarily contain BESS and have historically been viewed as a tool for aggregating infrastructure like BtM solar PV, electric vehicles, heat pumps, etc. In this report, we consider only VPPs that would include BESS.

schemes for C&I customers are also opaque, so it is difficult to determine externally how much such investments might save a customer (Baxter, 2021).

Residential BtM

In contrast to C&I batteries, SolarPower Europe (2024b) expects the pace of residential BtM BESS deployment in Europe to remain relatively stable over the rest of the 2020s, while EASE and LCP Delta (2025) anticipate a brief decline in the next two years. Some countries have reduced or eliminated their support mechanisms (grants, tax exemptions, tax deductions, etc) as the deployment of residential BtM has accelerated (Kaps and Netessine, 2025), explaining the expected near-term decline.

Deployment of residential BESS is geographically varied (see Figure 1), with a strong correlation between deployment and the degree of support or subsidy countries provide (SolarPower Europe, 2024b).

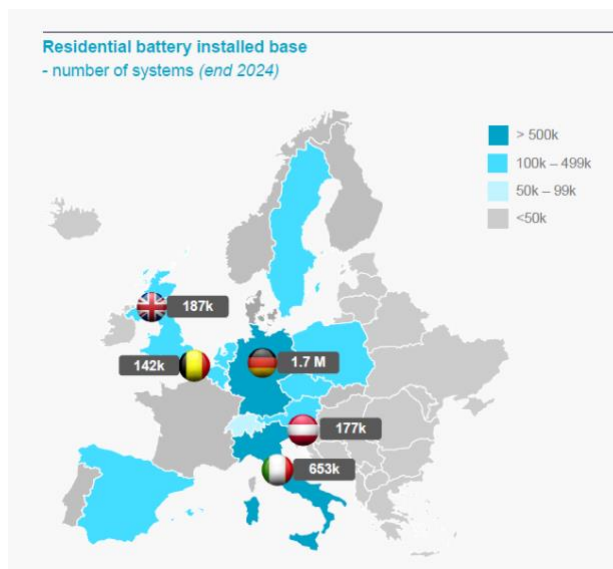


Figure 1: Residential BtM BESS by Country (EASE and LCP Delta, 2025).

In addition to subsidy schemes, there are also non-market effects driving residential BESS uptake. (Kaps and Netessine, 2025) found that in Germany, on average, households with solar PV placed the value of adding BESS at €0.50/MWh, showing the impact of non-monetary drivers. In Germany, with a FiT, this amount proved sufficient to clear the investment hurdle of residential BESS during the analysed period (2018-2022). There could thus be scope for households in countries without FiTs to invest in BtM BESS as battery costs drop before these projects necessarily reach the break-even point.

3. Co-Located BESS

Europe currently has around 1.75 GW of co-located BESS and VRE, around 1 GW of which was installed in 2024 (EASE and LCP Delta, 2025). Germany and Italy are the largest markets for co-location.⁶ SolarPower Europe (2024) anticipates that co-location will soon become the industry standard for VRE. However, in a study conducted by Pexapark (2023), only 20% of BESS developers surveyed were currently engaged with a co-located project.

One of the most obvious benefits of co-location is that the VRE and BESS share a grid connection. At a time when projects in many European countries are facing increasingly long grid connection timelines, this can enable BESS projects to come to market faster and reduces the CAPEX of installing BESS (Bush, 2024). Resultantly, co-location will be best-suited to countries where the cost of grid connection is very high (Bush, 2024). One study by Aurora Energy Research identified Germany, Ireland, Poland, and Hungary as markets of interest for co-location (Fragkiadaki, 2024).

There are three main ways to link VRE and BESS, visible in Figure 2 (Pexapark, 2023). There are few technical limitations for where the meter in such systems can be located, but this is defined by regulatory structures in each member state (Elexon, 2023).

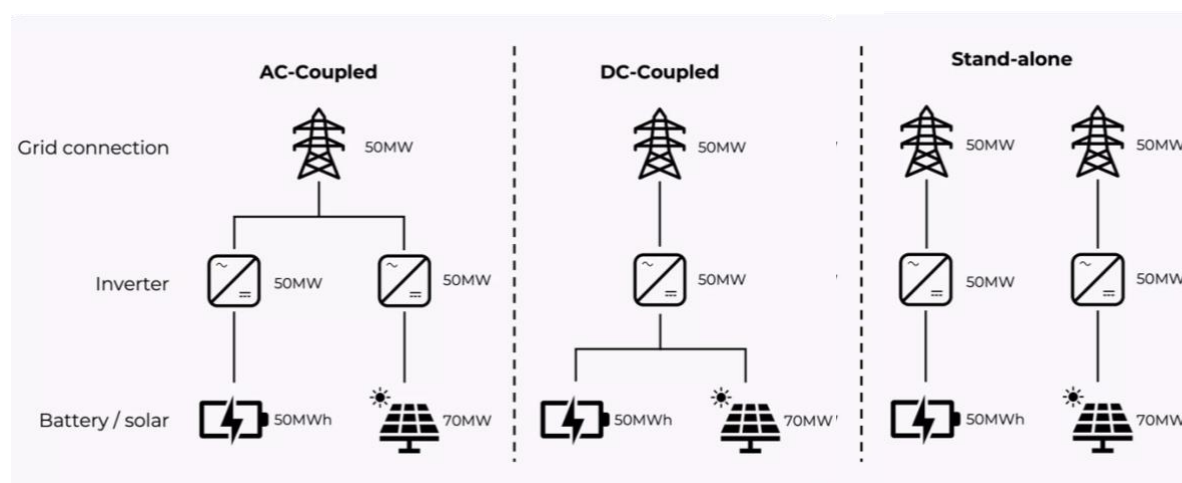


Figure 2: Types of Connection for BESS and VRE (Hortop, 2023)

AC-coupling has historically been the most popular means of connecting projects because it enables independent financing and operation of the VRE and the BESS (Pexapark, 2023). BESS profits are often limited in this design as the VRE generally receives priority access to the grid and discharges whenever it generates. Projects could also be hybrid AC-coupled, meaning they are operated together to maximise total site profit. DC-coupling reduces overhead site costs by eliminating the need for two inverters (Hortop, 2024), but it prevents the BESS from providing some frequency regulation services.

⁶ This includes all forms of co-located generation, representing BESS with VRE and BESS with thermal generators.

Generators and storage have competing siting requirements: generators are most profitable at the sites with the best possible weather output; BESS relies on being able to charge using inexpensive power and discharge when prices are high (Apostolopoulou and Poudineh, 2024).

Academic analyses have broadly deemed co-location unprofitable (e.g. Sihvonen, Annala and Honkapuro, 2024; Sheridan and Conlon, 2021; Biggins *et al.*, 2023). These results do not necessarily predict the future of co-located deployment, partly because steadily declining lithium-ion costs have made projects more attractive (BloombergNEF, 2025). Jafari, Botterud and Sakti (2020) found that the breakeven rate for co-located BESS was for lithium-ion battery costs between \$50-115/kWh of storage capacity, a territory battery costs crossed into in 2024 (BloombergNEF, 2025).

Another explanation is that in some regulatory landscapes, VRE generators cannot receive subsidy payments when charging co-located BESS (Uibleisen and Groneberg, 2025).⁷ Historically, this subsidy has generally been more profitable than what the BESS could earn (Sihvonen, Annala and Honkapuro, 2024).

However, with the number of negative-price hours in the EU increasing rapidly (Tani and Millard, 2024), Regulators in some member states (like Germany) have removed VRE subsidies during periods when the electricity price is negative (Uibleisen and Groneberg, 2025). This may make co-location much more appealing as there would be limited foregone revenue for the generator if the BESS is charged when prices are negative. It is unclear, however, whether or how other countries may modify their rules regarding co-location. At the moment, most Contracts for Difference auctions are open only to pure generators, implicitly inhibiting (or even barring) co-located participation regardless of how they treat negative price periods (SolarPower Europe, 2024a).

A final reason for this divergence is that the expected revenue streams for co-located batteries have evolved over time. Many co-location studies have focused on using BESS to reduce the impact of VRE forecasting errors (e.g. Frate *et al.* (2018), Yang *et al.* (2021)). This operation reduces penalties for the VRE generator and decreases the grid's overall need for some ancillary services, but it has not been profitable enough to justify BESS installation costs.

Co-located batteries could theoretically operate similarly to utility-scale BESS (especially with AC-coupling), participating in a range of markets (Hortop, 2022). Two caveats are that the BESS's ability to use its grid connection may sometimes be constrained by the VRE generator's output, and co-located batteries are blocked from participating in the same markets as utility-scale batteries in some member states.

Co-located projects' profitability and operation depends on the type of VRE generator. Solar generation is more predictable, broadly following daily trends, with output peaking in the early afternoon and waning come peak evening demand (Bush, 2024). In contrast, wind output is harder to predict and varies more significantly by season and day; it is also

⁷ Co-location may consequently become a more popular means of developing merchant projects (at least in the near term). This will depend, however, on the emergence of zero/negative pricing periods and the whether states respond to these periods of surplus by modifying the terms for co-location.

broadly uncorrelated to electricity demand. This makes solar a better complement to BESS than wind (Hortop, 2022), yet regulatory barriers mean the primary markets for co-location are currently more wind- than solar-dominant.

EU rules require co-located BESS to charge from the VRE generator at least 75% of the time annually to be eligible for aid funding (European Commission, 2023). Thus, most of the battery's power is likely to come from the VRE generator, largely eliminating any questions about the emissions potential of co-located BESS (beyond embodied carbon emissions).

4. Conclusions

Gaining a clear perspective on the deployment of these batteries to date (especially BtM BESS) has not been simple. In addition to limited data availability on BESS deployment, little focus has been placed academically on hybrid storage assets, meaning much of the content in this briefing paper has come from grey literature. These sources often presented conflicting information about the scale of regulatory barriers and did not distinguish between what could technically be possible for these projects and what is truly possible in the current EU landscape.

From an economic perspective, the ideal means of deploying BESS would be at utility-scale, enabling these batteries to operate in all markets legally open to them. Such batteries do not suffer from locational requirements in the same way as hybrid storage assets. The marginal cost of providing services from utility-scale BESS is also lower than for BtM BESS due to economies of scale (Scrimshire and Stephan, 2024).

However, the developers of utility-scale BESS are not necessarily the same as those of co-located BESS and are certainly not the same as those for BtM storage. This leaves room for non-financial incentives to affect the deployment of hybrid storage assets. While environmental considerations and the value of backup power are likely to drive BtM deployment, co-located BESS is likely to be deployed if it can reduce a VRE developer's exposure to negative-price periods.

The deployment of hybrid storage assets may alter the value proposition for utility-scale BESS. Any encroachment of hybrid storage assets on utility-scale profitability will depend on the scale of the regulatory barriers all batteries continue to face. It is currently unclear whether BtM projects will in future be used primarily to shift self-generated VRE power across time or will take on a greater role in the market. This may partly become a question of geography, with some countries (as Germany does) creating favourable conditions for hybrid storage assets while others block access.

The introduction of the EU's Clean Industrial Deal could prove quite significant for the deployment of energy storage more broadly. The European Commission's (2025) Action Plan for Affordable Energy highlights the intention to "address the remaining barriers that hamper demand response and storage services in the internal market." These modifications will be tied to state aid for electricity development, but their precise

impact on hybrid storage assets is not yet clear. State aid requirements will also make it easier to incentivise low-carbon flexibility over thermal generators in mechanisms like CMs. Linking these reforms to state aid requirements could improve their efficacy compared to other schemes designed to reduce barriers (such as double taxation), but this will become clearer once the Commission publishes its revised State aid framework later in 2025. The Electricity Market Design reforms also require all member states to measure their current deployment of low-carbon flexibility and forecast their needs as decarbonisation progresses (European Commission, 2024).

With wholesale markets expected to form the largest share of utility-scale BESS revenue in future, hybrid storage assets' access to this market (and their potential to cannibalise it) will have a fundamental impact on the relationship between these forms of storage. ACER (2025) has submitted a proposal to allow all demand side response (DSR) to participate in wholesale markets, but the implementation of such regulatory changes is still unclear.

Over time, as the cost of BESS continues to decline, it is likely that BtM and co-located BESS will become increasingly viable investments. Over time, VPPs aggregating BtM BESS or regulation opening new markets to these types of batteries should aid this shift. Fundamentally, however, unique factors driving the sizing, location, and operation of hybrid storage assets will likely diminish their profitability relative to utility-scale storage.

While the deployment of hybrid storage assets remains nascent in many member states, their (potentially, very positive) disruptive potential is significant, provided regulatory and market conditions evolve favourably. We would recommend, however, that the EIB explore this subject in more depth and carefully consider any projects of this nature before deciding to deploy capital. Given the wide variance across the EU, specific countries of interest should be examined in greater depth to understand the specific legal and regulatory context related to deploying hybrid storage assets.

5. List of Abbreviations

Abbreviation	Meaning
AC	Alternating current
ACER	Agency for the Cooperation of Energy Regulators
BESS	Battery energy storage system
BtM	Behind-the-meter
CAPEX	Capital expenditures
C&I	Commercial and industrial
CM	Capacity market
DC	Direct current
DSR	Demand side response
EASE	European Association for Storage of Energy
EU	European Union
EV	Electric vehicle
FCR	Frequency control reserve
FiT	Feed-in-tariff
GW	Gigawatt
GWh	Gigawatt-hour
kWh	Kilowatt-hour
MWh	Megawatt-hour
PPA	Power Purchase Agreement
PV	Photovoltaic
UK	United Kingdom
VPP	Virtual power plant
VRE	Variable renewable energy

6. References

- ACER (2023) *Demand response and other distributed energy resources: what barriers are holding them back? 2023 Market Monitoring Report*, ACER. Available at: https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER_MMR_2023_Barriers_to_demand_response.pdf (Accessed: 14 April 2025).
- ACER (2025) *New network code on demand response will further advance the energy transition*, ACER. Available at: <https://www.acer.europa.eu/news/new-network-code-demand-response-will-further-advance-energy-transition> (Accessed: 14 April 2025).
- Apostolopoulou, D. and Poudineh, R. (2024) 'Coupling storage and renewables: in the physical or virtual world?', *Oxford Energy Forum* [Preprint], (140). Available at: <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/04/OEF-140-Powering-the-Future.pdf> (Accessed: 10 April 2025).
- Bali, V. (2025) *Europe Virtual Power Plant VPP Market will grow at a CAGR of 21.1% from 2024 to 2031.*, *Cognitive Market Research*. Available at: <https://www.cognitivemarketresearch.com/regional-analysis/europe-virtual-power-plant-vpp-market-report> (Accessed: 24 April 2025).
- Baxter, R. (2021) *Energy Storage Financing: Project and Portfolio Valuation*. SAND2021-0830, 1817849, 698993. Sandia National Laboratories, pp. SAND2021-0830, 1817849, 698993. Available at: <https://doi.org/10.2172/1817849>.
- Biggins, F.A.V. et al. (2023) 'The economic impact of location on a solar farm co-located with energy storage', *Energy*, 278, p. 127702. Available at: <https://doi.org/10.1016/j.energy.2023.127702>.
- BloombergNEF (2025) 'Global Investment in the Energy Transition Exceeded \$2 Trillion for the First Time in 2024, According to BloombergNEF Report', *BloombergNEF*, 30 January. Available at: <https://about.bnef.com/blog/global-investment-in-the-energy-transition-exceeded-2-trillion-for-the-first-time-in-2024-according-to-bloombergnef-report/> (Accessed: 20 February 2025).
- Bush, J. (2024) *Co-location: what is the impact on future battery revenues?*, *Modo Energy*. Available at: https://modoenergy.com/research?region=%255B%2522gb%2522%255D&search=%2522co-location%2522&view=%2522reference_library%2522&post=%2522forecast-pro-april-24-co-location-battery-energy-storage-solar-wind-ac-dc-coupling-grid-connection-revenue-impact-wholesale%2522 (Accessed: 25 April 2025).
- Directorate-General for Energy (2023) *Staff working document on the energy storage - underpinning a decarbonised and secure EU energy system*, *European Commission*. Available at: https://energy.ec.europa.eu/publications/staff-working-document-energy-storage-underpinning-decarbonised-and-secure-eu-energy-system_en (Accessed: 1 January 2025).
- EASE (2023) 'Business Case and Taxonomy of Behind-the-Meter Battery Energy Storage Systems in Europe', *EASE Storage*. Available at: <https://ease-storage.eu/publication/businesscasetaxonomy/> (Accessed: 11 April 2025).
- EASE and LCP Delta (2025) *EMMES 9.0 - March 2025*. EASE. Available at: <https://ease-storage.eu/publication/emmes-9-0-march-2025/> (Accessed: 15 April 2025).
- Elxon (2023) *Metering Dispensations and Co-Located Generation*, *BSC Digital Code*. Available at: <https://bscdocs.elxon.co.uk/guidance-notes/metering-dispensations-and-co-located-generation> (Accessed: 29 April 2025).

Energy Storage Ireland (2023) *Behind-the-Meter Storage White Paper*, Energy Storage Ireland. Available at: <https://www.energystorageireland.com/wp-content/uploads/2023/07/Energy-Storage-Ireland-Behind-the-Meter-Storage-White-Paper.pdf> (Accessed: 14 April 2025).

Energy Transition Expertise Centre (ENTEC) (2023) *Study on energy storage*, Publications Office of the EU. Available at: <https://op.europa.eu/en/publication-detail/-/publication/dfcaa78b-c217-11ed-8912-01aa75ed71a1/language-en> (Accessed: 1 January 2024).

European Commission (2023) *Commission Regulation (EU) 2023/1315 of 23 June 2023 amending Regulation (EU) No 651/2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty and Regulation (EU) 2022/2473 declaring certain categories of aid to undertakings active in the production, processing and marketing of fishery and aquaculture products compatible with the internal market in application of Articles 107 and 108 of the Treaty (Text with EEA relevance)*, European Union. Available at: <https://eur-lex.europa.eu/eli/reg/2023/1315/oj/eng> (Accessed: 11 April 2025).

European Commission (2024) *Electricity market design*, European Commission. Available at: https://energy.ec.europa.eu/topics/markets-and-consumers/electricity-market-design_en (Accessed: 1 January 2024).

European Commission (2025) 'COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Action Plan for Affordable Energy Unlocking the true value of our Energy Union to secure affordable, efficient and clean energy for all Europeans'. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52025DC0079&qid=1741780110418> (Accessed: 7 May 2025).

European Environment Agency (2022) *Annex 6: Vehicle-Grid Integration*, European Environment Agency. Available at: <https://www.eea.europa.eu/publications/transport-and-environment-report-2022/term-2022-annex-6>.

Eurostat (2024) *Electricity and heat statistics*, Eurostat. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_and_heat_statistics (Accessed: 1 May 2025).

Fragkiadaki, Z. (2024) 'Germany, GB, the Ireland I-SEM, and Poland top four markets for renewables and battery co-location in Europe', *Aurora Energy Research*, 13 June. Available at: <https://auroraer.com/country/europe/germany-great-britain-the-ireland-i-sem-and-poland-top-four-markets-for-renewables-and-battery-co-location-in-europe/> (Accessed: 10 April 2025).

Frate, G.F. et al. (2018) 'Techno-economic sizing of a battery energy storage coupled to a wind farm: an Italian case study', *Energy Procedia*, 148, pp. 447–454. Available at: <https://doi.org/10.1016/j.egypro.2018.08.119>.

de Giovanni, A. and Warren, B. (2024) *Four factors to guide investment in battery storage*, EY. Available at: https://www.ey.com/en_gl/insights/energy-resources/four-factors-to-guide-investment-in-battery-storage (Accessed: 1 January 2024).

Hortop, W. (2022) *Co-location explained*, Modo Energy. Available at: https://modoenergy.com/research?region=%255B%2522gb%2522%255D&search=%2522co-location%2522&view=%2522reference_library%2522&post=%2522co-location-battery-energy-storage-explained%2522 (Accessed: 25 April 2025).

Hortop, W. (2023) *Co-location of battery energy storage: AC/DC*, Modo Energy. Available at: https://modoenergy.com/research?region=%255B%2522gb%2522%255D&search=%2522co-location%2522&view=%2522reference_library%2522&post=%2522co-location-battery-energy-storage-solar-ac-dc-coupling%2522 (Accessed: 25 April 2025).

Hortop, W. (2024) *Co-location: what are the costs and benefits of DC-coupling? - Research | Modo Energy, Modo Energy*. Available at: <https://modoenergy.com/research/co-location-battery-energy-storage-solar-dc-coupling-benefits> (Accessed: 25 April 2025).

Jafari, M., Botterud, A. and Sakti, A. (2020) 'Estimating revenues from offshore wind-storage systems: The importance of advanced battery models', *Applied Energy*, 276, p. 115417. Available at: <https://doi.org/10.1016/j.apenergy.2020.115417>.

Joint Research Centre (JRC) (2025) *European Energy Storage Inventory, JRC Smart Electricity Systems*. Available at: <https://ses.jrc.ec.europa.eu/storage-inventory> (Accessed: 1 May 2025).

Kaps, C. and Netessine, S. (2025) 'Residential Battery Storage - Reshaping the Way We Do Electricity'. Social Science Research Network. Available at: <https://doi.org/10.2139/ssrn.4219247>.

Marra, I. and Kleefeld, N. (2024) *Wie tausende vernetzte sonnenBatterien das Stromnetz stabilisieren, Sonnen*. Available at: <https://sonnen.de/blog/wie-tausende-vernetzte-sonnenbatterien-das-stromnetz-stabilisieren/> (Accessed: 24 April 2025).

Openvolt (2024) *The State of Smart Meter Data Access Across Europe: Challenges, Opportunities, and Country-by-Country Insights · Openvolt | The API for Smart Meter Data, Openvolt*. Available at: <https://www.openvolt.com/blog/post/the-state-of-smart-meter-data-access-across-europe> (Accessed: 28 April 2025).

Pexapark (2023) 'Renewables-Plus-Storage Co-Location Trends: Hybrid PPAs and More'. Pexapark.

RE-Source (2020) *On-Site Renewable Electricity and Storage for Corporates: Business Models & Policy Framework, RE-Source*. Available at: https://resource-platform.eu/wp-content/uploads/202011-Re-Source-Force_On-Site-Generation-and-Storage_Challenges-and-Barriers-web-compressed_compressed-1-3.pdf (Accessed: 15 April 2025).

Scrimshire, Q. and Ferrell, G. (2024) *Virtual Power Plants with Geoff Ferrell (Senior Vice President @ sonnen, Inc), Modo Energy*. Available at: <https://modoenergy.com/research/channels/transmission?wchannelid=vtx0dp52da&wmediaid=m7y4tpic1b> (Accessed: 14 April 2025).

Scrimshire, Q. and Stephan, L. (2024) *BESS and the German energy market with Lars Stephan (Senior Manager of Policy and Market Development @ Fluence) - Transmission, Modo Energy*. Available at: <https://modoenergy.com/research/channels/transmission?wchannelid=vtx0dp52da&wmediaid=5pqxf6Oglg> (Accessed: 14 April 2025).

Sheridan, C. and Conlon, M. (2021) 'A Techno-Economic Evaluation of Battery Energy Storage Systems co-located with Wind in the Irish Integrated Electricity Market', in *2021 56th International Universities Power Engineering Conference (UPEC). 2021 56th International Universities Power Engineering Conference (UPEC)*, pp. 1–6. Available at: <https://doi.org/10.1109/UPEC50034.2021.9548207>.

Sihvonen, V., Annala, S. and Honkapuro, S. (2024) 'Co-locating PV and BESS in an energy community of commercial and industrial prosumers', in *2024 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE). 2024 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE)*, pp. 1–6. Available at: <https://doi.org/10.1109/ISGTEUROPE62998.2024.10863621>.

SolarPower Europe (2024a) *Electricity Market Design Reform: Implementation Guidance from the Solar Sector, SolarPower Europe*. Available at: https://api.solarpowereurope.org/uploads/EMD_implementation_guidance_final_e5a3aee317.pdf?updated_at=2024-07-16T13:32:58.173Z (Accessed: 15 April 2025).

SolarPower Europe (2024b) *European Market Outlook for Battery Storage 2024-2028*. SolarPower Europe. Available at: https://api.solarpowereurope.org/uploads/1424_SPE_BEES_report_12_mr_84bdb6c5ae.pdf (Accessed: 10 April 2025).

Sonnen Content Team (2022) *Smart Meter – ein wichtiger Baustein für die Energiewende, sonnen*. Available at: <https://sonnen.de/wissen/smart-meter-ein-wichtiger-baustein-fuer-die-energiewende/> (Accessed: 24 April 2025).

Tani, S. and Millard, R. (2024) *Negative European energy prices hit record level*, *The Financial Times*. Nikkei. Available at: <https://www.ft.com/content/1f94d0b4-c839-40a2-9c8d-782c00384154> (Accessed: 1 January 2024).

Tickler, P. (2025) *The economics of behind-the-meter battery storage. Part 1: Reducing your energy bill*, *Gridcog*. Available at: <https://www.gridcog.com/blog/the-economics-of-behind-the-meter-battery-storage-part-1-reducing-your-energy-bill> (Accessed: 14 April 2025).

Uibeleisen, M. and Groneberg, S. (2025) 'German Battery Storage on a Rise - Recent developments and current legislative change', *McDermott Will & Emery*. Available at: <https://www.mwe.com/insights/german-battery-storage-on-a-rise/> (Accessed: 28 April 2025).

Yang, Y. et al. (2021) 'Impact of forecasting error characteristics on battery sizing in hybrid power systems', *Journal of Energy Storage*, 39, p. 102567. Available at: <https://doi.org/10.1016/j.est.2021.102567>.

Zhu, S. (2023) 'Analysis of energy storage policies in key countries - Germany: Government's Economic Measures Driving the Behind-the-Meter (BTM) Energy Storage Market', *Interact Analysis*. Available at: <https://interactanalysis.com/insight/analysis-of-energy-storage-policies-in-key-countries-germany/> (Accessed: 14 April 2025).