BA-CS-061

REV: April 14, 2025

Alfa Hailemariam Abraha

Alfonso Ruibal

Berni Mayer

Michal Sobczyk

Pieter Braakenburg

Investment on Front-of-the-Meter BESS Application: Regulatory, Revenue Stacking, Operational and Technical Considerations

Introduction

Investments in Battery Energy Storage Systems (BESS) offer a strategic opportunity for investors seeking to capitalize on the evolving energy landscape. BESS plays a crucial role in enhancing grid stability by providing rapid response capabilities to balance supply and demand fluctuations, thereby mitigating the risk of power outages, increasing the overall system efficiency of transmission and distribution grids, as well as deferral of investment on grid expansion requirements. The significant reduction in battery technology costs, combined with increasingly favorable regulatory environments in selected markets, enhances the economic attractiveness of investing in BESS. Therefore, investments in BESS are likely to increase over the course of the years, and as indicated in [**Exhibit 1**], worldwide BESS capacity, mainly driven by utility installations, is expected to quintuple by 2030 **[10]**. Investors should closely consider BESS opportunities, as the market's ongoing growth presents the potential for attractive returns and strategic positioning within the expanding clean energy landscape.

Alfa Abraha, Alfonso Ruibal, Berni Mayer, Michal Sobczyk, Pieter Braakenburg, prepared the original version of this note Investment on Front-of-the-Meter (FTM) BESS Application: Regulatory, Revenue Stacking, Operational and Technical Considerations BA No. BA-CS-061, reviewed by B.A Mariano Rubio & Dr. Garima Shukla, as the basis for class discussion. Only for B.A open case study on 2025.04.16.

Despite the potential growth and opportunities, utility-scale BESS remains a developing market sector with certain risks—such as disruptive technological evolution, regulatory uncertainty and operational complexities.

When assessing investments in BESS, investors should, therefore, consider several key factors. Some of the main aspects and questions to be addressed are as follows:

- **Technology and Supply Chain**: Selecting the appropriate battery technology significantly impacts project success. Investors should consider factors such as battery chemistry, energy density, cycle life, efficiency, safety profiles and scalability, among others. As a result, the availability and selection of BESS suppliers are very crucial. ***Which criteria are most important when selecting BESS suppliers?***

- **Regulatory and Policy Framework**: Supportive policies and incentives can enhance the attractiveness of BESS investments. It is essential to evaluate the regulatory framework governing energy storage, including tariffs, subsidies, and grid interconnection standards. ***How does the regulatory and policy landscape regulate BESS and is it conducive for investment in BESS?***
- **Operational Aspects**: An asset owner can choose between various revenue strategies, ranging from long-term contracted cash flow to fully merchant business cases. Capturing BESS revenue potential requires specialist trading & optimization capabilities, which a BESS owner may not have in-house. ***What is the most sensible operational approach for an investor, and why?***
- **Revenue Streams**: BESS can generate substantial revenue by optimizing multiple income streams, including energy arbitrage, frequency regulation services, and capacity payments. ***Which market mechanisms can BESS participate in, and which revenue streams can be generated? Is participation in multiple markets (revenue stacking) possible?***

Based on the four main factors mentioned above, this case study will provide **the protagonist, an investor interested in investing on the BESS market**, with an overview of FTM BESS deployment opportunity considerations, with a cross reference in six markets: Germany, the United Kingdom (UK), Australia (NEM), Chile, Texas (ERCOT) and California (CAISO).

Regulatory and Policy Framework for BESS

Regulatory and policy framework is a critical factor for the deployment of BESS as it influences profitability, market accessibility and risk appetite. The attractiveness of such investments will highly depend on whether BESS can access wholesale energy markets and provide grid services, whether revenue generation from multiple market participation is possible, and how grid fees, incentives, and permitting requirements are set up.

A well-structured regulatory environment supports BESS investment by allowing market participation, minimizing double charging, providing incentives, and ensuring a streamlined permitting process. Investors must carefully evaluate the regulatory landscape before committing capital to specific markets.

Market Participation & Revenue Stacking

The ability of BESS to participate in wholesale and ancillary service markets varies by region. While Texas, California, and the UK provide open access to these markets, Germany requires prequalification for participation. Chile remains an evolving market with partial access, making revenue generation more uncertain. Revenue stacking opportunities—where BESS can earn from multiple sources, such as frequency response, arbitrage, and capacity markets—are strongest in Texas, California, and the UK. In Germany, revenue stacking is possible but more restricted due to regulatory complexity.

Grid Fees & Double Charging

Historically, grid fees and double charging (where BESS is charged for both storing and discharging electricity) were barriers to investment. However, Germany has eliminated double charging for front-of-the-meter BESS, aligning with other key markets, such as Texas, California, the UK, and Australia. Chile remains a market where double charging may still be an issue, impacting investment attractiveness.

Incentives & Subsidies

Government incentives significantly impact investment viability by improving financial returns. Key incentive programs for each market are summarized below:

- **Texas (ERCOT), California (CAISO) – U.S. Inflation Reduction Act (IRA) 2022:**
    - Offers a 30% Investment Tax Credit (ITC) for standalone energy storage projects **[3]**.
- **UK – Contracts for Difference (CfD) & Capacity Market:**
    - The UK government has included energy storage within the Capacity Market, allowing BESS operators to receive payments for providing long-term reliability.
    - Additional funding through Contracts for Difference (CfD) may be available for co-located renewable and storage projects.

- **Germany – EU Green Deal & KfW Battery Storage Grants:**
    - BESS is indirectly supported under the EU Green Deal, though direct subsidies are uncertain, shifting political priorities under the new government.
    - The KfW (Kreditanstalt für Wiederaufbau) grants support battery storage co-located with solar PV.
- **Australia – State-Level Battery Incentives:**
    - Some states offer financial incentives, such as the South Australia Home Battery Scheme and Victorian Battery Rebate, to promote residential and commercial energy storage.
- **Chile – Limited National Support:**
    - No large-scale national incentives, but emerging pilot projects are supported by regional energy transition programs.

Permitting & Interconnection Speed

Permitting and interconnection speeds vary significantly by market. Texas and Australia offer fast approvals, while California and the UK have moderate permitting times. Germany and Chile remain slow, with bureaucratic obstacles often causing long delays. In Germany, it takes between 12 and 24 months from project request until operations start.

Utility Ownership & Market Structure

Market structure also affects investment potential. In deregulated markets like Texas and California, utilities are restricted from owning storage assets to ensure fair competition. In contrast, markets like Germany, Australia, and Chile allow utility ownership of BESS, which can limit private sector participation in some cases.

As summarized in [**Exhibit 2**], the regulatory landscape for BESS varies significantly across markets, shaping investment opportunities and risks. Texas, California, and the UK present favorable conditions with open market access, strong revenue stacking opportunities, and established incentive schemes. These factors contribute to a more stable and predictable investment environment. Germany offers access to wholesale and ancillary markets but requires prequalification, and regulatory uncertainty around incentives remains a concern. Additionally, slow permitting processes can delay project timelines. Australia has a more fragmented approach, with state-level incentives playing a crucial role in storage deployment. Chile is an emerging market where regulatory structures are still evolving. While opportunities exist, challenges, such as permitting delays, grid bottlenecks, and the absence of strong financial incentives, increase investment risks.

BESS Operational Model

There are different optimal revenue models for BESS owners, ranging from (i) a fully merchant approach, (ii) long-term contracted revenues, or (iii) a hybrid model of the two. A merchant business model provides very little certainty of revenue, whereas long-term contracted revenues provide more certainty, downside protection and are simpler from an operational perspective. This comes at a cost; revenues are significantly lower versus a merchant business case. Each strategy will put different requirements on the asset owner when it comes to operating the asset to generate revenues. The type of offtake contracts also determines the bankability and economic feasibility of a BESS project.

What is meant by 'optimizing' a BESS asset?

A merchant business case of a BESS system often relies on various revenue sources, so-called revenue stacking. This requires an asset owner to combine various data sources, such as market data, weather data and BESS asset information, and process all this information into a trading strategy for the BESS system. This trading strategy needs to be sent to the respective (electricity) markets to place orders on these markets, after which trades are effectuated. This, in turn, leads to a charging/discharging schedule, which the BESS asset needs to execute, as summarized in [**Exhibit 3**].

Given the vast amount of information that needs to be processed, this process is largely automated using algorithms, AI & machine learning. This is a complex process which requires specialist trading & optimization capabilities as well as deep knowledge of the grid code and workings of electricity and ancillary services markets in each country. BESS asset owners typically don't have these skills in-house and therefore need to contract these services rather than building these capabilities in-house. A high proportion of BESS projects are being operated using 3rd party offtake contracts, which possess the specialist trading & optimization capabilities required to capture BESS revenue potential. A party which provides these trading and optimization skills is also known as an **'Optimizer'**. Optimizers can be grouped into three different categories: Utility trading desks, Energy traders and 'Trading as a Service' providers **[9]**. Characteristics of each category and examples of such providers are indicated in [**Exhibit 4**].

What revenue structures are available to an asset owner?

Four general approaches, as summarized in [**Exhibit 5**], are typically used to secure revenues for a BESS asset owner **[7] [8]**:

- **Fixed Tolling agreement:** A tolling agreement is a contract between a BESS asset owner and an Optimizer. The main responsibilities of the BESS owner are the technical setup, administrative aspects and asset availability. The Optimizer pays a fixed price for multiple years to the asset owner, providing stability of revenues to the BESS owner, thus improving bankability. The Optimizer may achieve higher revenues, and this upside is retained by the Optimizer.
- **Floor:** A floor price is a contract type whereby a BESS owner makes a minimum revenue when using the optimization service of an Optimizer. This amount is typically contractually fixed but can be variable in certain scenarios. The guaranteed revenue is lower than in a tolling agreement because the asset owner maintains the upside potential, while the optimizer assumes the downside risk. The guaranteed minimum revenue can increase depending on the asset's trading outcome and the contractually fixed revenue split.
- **Cap & floor:** Floor prices might be capped; this means that the upside potential is limited to a certain amount.
- **Fully merchant:** In a fully merchant setup, the BESS owner is exposed to the full downside and the full upside revenue potential. If the BESS performs well commercially, this model captures the highest returns. It, however, has no downside protection if the asset's performance is affected by unfavorable market conditions. In a fully merchant setup, it may be more challenging to raise project finance debt given the higher uncertainty around future revenues. Given that there is no fixed price in this setup, there is a more prominent role for 'Trading as a Service' providers as there is no guaranteed revenue and, therefore, less need for a stronger balance sheet of the Optimizer.

Risks and opportunities related to operational and revenue structure setup will vary depending on the maturity of the targeted investment market, complexity of market structure and availability of service providers.

Revenue Streams and Revenue Stacking

The profitability of a BESS system pretty much depends on how well revenue can be generated, how many revenue streams are available and how well these revenue streams could be optimized. An investor/developer will, therefore, need to analyze and understand the available revenue streams for building up a business case for a BESS installation. Different markets offer different possible revenue streams, most commonly, in the form of wholesale energy arbitrage, ancillary services and capacity/balancing markets, among others.

For the purpose of this case study, an example of the revenue streams and revenue potential of a 100MW/200MWh Front-of-the-Meter BESS across different markets will be shown. The technical and financial assumptions considered for the analysis are summarized in [**Exhibit 6**].

United Kingdom (UK)

UK's market provides multiple revenue opportunities for BESS: energy arbitrage in the wholesale and balancing markets, ancillary services (frequency response), and the Capacity Market. The UK power system has seen growing renewable penetration, leading to periods of both negative prices (surplus wind/solar) and price spikes (during low renewable output).

[**Exhibit 7**] illustrates the revenue stacking concept for a UK 2h BESS, flexibly shifting between services to maximize total income. Notably, frequency response (dynamic services) and wholesale arbitrage provided the bulk of upside in this instance, while the capacity payment offers a steady baseline. Overall, a 100 MW/200 MWh BESS in the UK can stack energy trading, frequency services, balancing mechanism trades, and capacity payments. **Historically, annual revenues around €100k–170k per MW have been observed under volatile conditions.** Going forward, an investor should model lower ancillary prices (due to competition) but steady capacity income and continued volatility-driven trading gains, especially as coal plants close and more renewables drive a gap in intraday prices **[11]**.

Australia

Australia's NEM (particularly states like South Australia, Victoria, NSW) has emerged as a lucrative but changing arena for battery storage. Revenue streams include energy arbitrage, Frequency Control Ancillary Services (FCAS), and increasingly fast contingency services. There is no central capacity market in the NEM (it is an energy-only market), though some state-driven contracts exist. The market spans five state regions with sometimes divergent prices and is known for its volatility (e.g. negative prices during midday solar peaks, price spikes during evening peaks or grid events).

According to a 2024 analysis, only ~27% of Australian large-scale battery revenue has come from energy market trading, as ancillary services were more profitable. However, as more storage comes online and FCAS prices normalize, arbitrage is expected to grow in importance. Longer-duration batteries (4+ hours) coming by 2026 could increase competition in arbitrage but also capture more multi-hour price spread opportunities. The NEM has multiple FCAS markets: Regulation (raise/lower, for continuous frequency control), and Contingency (fast, slow, delayed for major events). These have been the primary cash cow for batteries, which provide ultra-fast response impossible for conventional generators. About 73% of battery revenue in recent years came from FCAS (50% from contingency FCAS, ~23% from regulation FCAS), reflecting how profitable these services were for early projects. As more batteries (and some demand response) participate, FCAS prices have moderated, but new services are being introduced. Nonetheless, FCAS remains a major revenue stream: a 100 MW BESS can bid some capacity into regulation and some into contingency markets simultaneously (if not providing energy at that moment). By optimizing across 8 FCAS markets and energy, batteries maximize income.

In summary, a 100 MW/200 MWh BESS in Australia can earn substantial revenue, especially if merchant-operated in FCAS and arbitrage. A high-risk investor in the NEM would focus on maximizing exposure to FCAS price spikes and energy volatility (potentially foregoing any off-take contracts). Historical evidence shows high rewards but also the trend that early profits attract competitors, driving down ancillary prices – a crucial risk to the model. Diversifying revenue (across multiple FCAS services and arbitrage) is key to sustaining returns in Australia's dynamic regulatory landscape.

Texas (ERCOT)

Texas's ERCOT market is an energy-only market with no capacity payments and high price volatility. Real-time electricity prices can skyrocket during scarcity (formerly up to $9,000/MWh, now capped at $5,000/MWh), and even approach $0 or negative during low demand or high wind output. BESS in ERCOT primarily earn revenue through energy arbitrage and ancillary services (called "Ancillary Services (AS)" in ERCOT, including Regulation Up/Down and reserve products).

A 2-hour BESS in ERCOT cycles daily to exploit price spreads. Typically, it charges overnight or midday when wind and solar drive prices are down and discharges during late afternoon/evening when demand peaks and supply is tighter. Average spreads yield a base arbitrage income; for example, in 2022, day-ahead arbitrage contributed roughly 14% of battery revenues, but this share grew in 2023–24 as more batteries shifted to energy storage. The real allure in ERCOT is extreme event arbitrage. During scarcity events (e.g. summer heat waves or winter storms), real-time prices can max out at $5,000/MWh. A fully charged 100 MW battery that discharges during a one-hour $5,000/MWh event would gross $500,000 in that hour. As ERCOT's renewable fleet grows (wind/solar), the daily price shape is becoming more pronounced, improving arbitrage opportunities – but the average arbitrage revenue per kW is still moderate ($20–40/kW-year in recent years). The payoff is highly skewed to a few events, aligning with a high-risk, high-reward strategy.

Historically, ERCOT batteries earned the bulk of revenues (80–90%) from ancillary services like Regulation (fast up/down balancing) and Responsive Reserves. By the first half of 2023, 87% of ERCOT battery revenue came from AS (regulation and reserves). However, in 2024 a shift began, and as more batteries vied for limited AS capacity, clearing prices fell, and optimizers diverted some batteries to energy trading. Ancillary share dropped to ~60%, with energy making ~40% in H1 2024.

ERCOT profile requires robust optimization: real-time algorithmic trading to charge and discharge at optimal times, and careful selection of when to provide ancillary services versus energy (a constantly shifting optimization problem). Many ERCOT battery operators use AI-driven or quant trading approaches to maximize merchant revenue.

California (CAISO)

California's market, operated by CAISO, has seen rapid growth of BESS, now the largest single-region storage fleet in the world (~5 GW online by 2024). California's push for decarbonization (60% renewable by 2030, 100% clean by 2045) and several capacity shortfalls (e.g. Aug 2020 rolling blackouts) have driven aggressive procurement of batteries, often via long-term contracts. Thus, while the available revenue streams are similar to other markets – energy arbitrage, ancillary services (regulation, spinning reserve), and a form of capacity payment (Resource Adequacy - RA) – the majority of large BESS in California operate under contracts that guarantee a portion of their revenue. **For an independent high-risk investor considering CAISO, it's important to understand both the merchant opportunities and the RA contract structure because pure merchant storage is less common (though possible).**

A 100 MW/200 MWh in California could earn on the order of ~€90–135k when combining RA and market revenues in a "normal" year, with upside in stressed years. A high-risk investor might attempt a fully merchant operation, but in CAISO that is closer to a fully merchant with a twist – likely still selling RA capacity (because leaving that money on the table is hard to justify given it doesn't preclude trading). The revenue-maximizing approach is to secure an RA contract for baseline income and then optimize energy/ancillary dispatch to maximize profit on top of that (this is essentially a hybrid model).

Germany

Germany has an energy-only market without a capacity market (although the German regulator has plans to introduce this revenue stream in the near future), but it has well-established ancillary service markets, particularly the Frequency Containment Reserve (FCR), which is the primary frequency regulation. German (and European) batteries have focused on FCR because it offered high, stable revenues, paid as availability payments in competitive auctions. More recently, opportunities in the intra-day energy market arbitrage have increased due to renewable volatility (wind/solar swings) and European power price spikes as in 2021-2022. Germany (and adjacent EU markets) also procure secondary (aFRR) and tertiary (mFRR) reserves, which are opening up to batteries. For a 100 MW/200 MWh BESS in Germany, the main revenue pillars are FCR, aFRR, and wholesale energy trading. **A unique aspect in Europe is cross-border**

markets: a battery in Germany can potentially provide FCR to a common European pool and participate in EU-wide platforms for aFRR in the future, diversifying revenue.

The best German battery operators have earned ~€166k/MW-year by optimizing between FCR and aFRR markets. This likely involved placing capacity in whichever market was more profitable each day. A 2-hour BESS can provide aFRR (which typically requires 15 min sustain, well within 2h capability) and can switch between providing FCR and aFRR in different time blocks. Stacking both in the same hour is not possible on the same MW. So, the strategy is to dynamically allocate some MW to FCR, some to aFRR, or to energy trading. The tertiary reserve (mFRR) is activated less frequently and pays only when called, so batteries tend to prefer the primary and secondary, which pay for just being available.

By design, batteries participating heavily in FCR/aFRR can not simultaneously do energy arbitrage on those MW. However, when FCR prices drop (like in 2023) [**Exhibit 8**], operators start dedicating more capacity to arbitrage. In fact, by mid-2023, monthly revenues from spot market trading sometimes exceeded those from FCR for the first time. For example, in some months of 2023, a 1 MW/1 MWh battery could earn slightly more from energy trading than from FCR. This indicates that arbitrage is becoming an equal pillar of revenue **[12]**.

Germany offers a case of high initial ancillary revenues declining with saturation, pushing batteries to diversify into wholesale trading. A 100 MW/200 MWh BESS can still earn solid revenues (potentially ~€80–120k per MW-year in the mid-term, combining markets), but the strategy must be nimble, switching between FCR, aFRR, and arbitrage based on market signals. A high-risk investor in Germany would focus on an algorithmic approach to maximize total revenue: e.g., bid FCR in some blocks, if FCR price falls below expected energy arbitrage value then use the battery for energy in those hours, or bid aFRR if that pays more, etc. This continuous optimization is complex but essential, as single-market strategies (just FCR or just arbitrage) are less reliable now.

Chile

Chile is on the cusp of enabling large BESS revenues through a combination of energy market spreads and new capacity payments. While not as historically proven as other regions, the upside of being an early mover is evident – the first few 100 MW batteries in Chile could capture very high arbitrage and perhaps get generous capacity contracts. The high-risk strategy in Chile would be to go merchant initially (exploiting high evening peaks), while positioning to grab a capacity payment once the rules kick in. Many investors, however, may opt for hybrid approaches (partial PPAs or tolling) given Chile's evolving market. A BESS can pursue all available revenues: merchant trading and any capacity mechanism once available.

[**Exhibit 9**] provides a comparative snapshot of the revenue streams and estimated revenue potential of a BESS in each region. All values are approximate and based on recent historical data or current market conditions, assuming high-performance merchant operation. Higher end of ranges correspond to recent volatile market conditions or first-mover advantages, and lower end to more saturated/normal conditions.

Aspects and Considerations for BESS Supplier Selection

The selection of a BESS supplier is a critical decision that impacts the overall performance, cost-effectiveness, and reliability of an energy storage project. To ensure the best possible choice, suppliers must be evaluated based on multiple criteria [**Exhibit 10**]. A comprehensive assessment involves considering technical capabilities, pricing structure (CAPEX and OPEX), commercial conditions, delivery timelines, and additional factors, such as market fit, availability of service personnel and office of supplier in the envisaged market, innovation, and sustainability. The assessment is done with a target of optimizing the profitability and minimizing the risk of the investment.

Some of the key indicators to be considered are described as follows:

Technical Considerations

The technical evaluation of BESS suppliers should focus on key aspects that directly impact project performance and longevity. The initial screening criteria involve a few fundamental aspects. The first step is defining the appropriate battery chemistry, whether it be lithium-ion, sodium-sulfur, or flow batteries, to determine its suitability for the project.
Secondly, ensuring compliance with industry standards and certifications, such as IEC, UL, and IEEE, is essential for guaranteeing reliability and safety, as non-certified systems introduce significant project risks. Any missing certification is a risk to the project and the bankability of the asset.

Additionally, suppliers offer various scopes of supply, ranging from full turnkey EPC solutions to supply-only options. In emerging markets, opting for an EPC solution can reduce risks by consolidating responsibility under one stakeholder. However, in mature markets, experienced developers may prefer self-integration and purchasing components separately (BESS, PCS, EMS) to optimize costs. The most common approach is to split the scope of the project into a BESS supplier/integrator (supply and long-term warranties of the BESS, PCS and even MV skid) and a Balance of Plant contractor (civil work, mechanical installation and electrical works).

A comparative technical assessment of key performance metrics, such as, but not limited to, energy density (determining land requirements and hence project cost), availability (higher availability increasing revenue streams and hence project profitability), round-trip efficiency, power and energy at point of connection, energy retention and degradation, and scalability and modularity for future augmentation or oversizing of the asset, is required once a preselection of BESS suppliers has been done based basic screening criteria [**Exhibit 11**]. Beyond performance metrics, additional technical considerations, such as noise emission levels, should be looked at as this might impact the permitting procedure or require additional noise mitigation strategies. Depending on the requirements of specific markets, utility-scale energy storage systems are part of critical infrastructure, and cybersecurity is another crucial factor, which should be considered in the selection process.

Price Evaluation (CAPEX and OPEX)

Financial considerations play a key role in selecting a BESS supplier, and the total cost of ownership should be evaluated holistically. Capital Expenditure (CAPEX) includes upfront costs, such as hardware, installation, and commissioning. The costs of operation, i.e., Operational Expenditure (OPEX), consist of long-term costs, such as maintenance, software updates, warranty coverage, and component replacements. Comparing service offerings is complex as suppliers adopt different approaches to maintenance and warranty conditions. One of the most comprehensive metrics for cost assessment is the Levelized Cost of Storage (LCOS), which accounts for both CAPEX and OPEX. This metric provides a cost-per-unit measurement for stored and delivered energy, offering a more accurate representation of project cost-effectiveness.

Contractual Conditions

A proper assessment of the contractual terms and conditions, especially related to guarantee values, such as battery life cycles, degradation rates, and overall system performance, is needed. Some of the questions which should be answered include: Are the liquidated damages high enough to cover the expected revenue? Does the company usually fall into liquidated damages? Does the developer have any commitment with other entities (TSO) that could trigger penalties? Additionally, Long-Term Service Agreements (LTSAs) must define response times, uptime guarantees, and support availability, with liquidated damages clauses in place to mitigate performance risks.

Delivery Time and Supply Chain Considerations

The stability of a supplier's manufacturing and supply chain is crucial for ensuring timely project execution. Suppliers with robust and reliable sourcing networks minimize the risk of delays. Efficient logistics, including shipping, customs clearance, and on-site installation, significantly impact overall project success and should be carefully considered.

Additional Factors

Beyond technical, financial, and contractual considerations, several additional factors, such as track record and experience of suppliers in the target market, with proximity to service hubs and ability to provide local support, as well as ESG compliance, should be considered in the evaluation process.

Conclusion

As described in the introduction and throughout the case study, BESS installations and applications will grow over the foreseeable future due to changes and dynamics in the energy landscape. The push for electrification and increase of the non-dispatchable renewables share in the electricity mix are and will be creating opportunities and new business areas for BESS applications. Even though there is a growing market and new business opportunity for BESS, the opportunity considerations for investment in the BESS market is a complex process requiring establishing a good overview of the deriving factors and opportunities versus the risks associated with it. Questions related to market access, regulatory and policy landscape, revenue potential, supply chain, permitting and operational aspects, financing, risk appetite and investment strains need to be answered.

This case study has highlighted questions (as listed below) related to regulatory and policy landscape, revenue streams, revenue structures and operational set-up as well as supplier selection considerations. These considerations are by no means exhaustive and are meant to show a snapshot of the complexity.

1. Which criteria are most important when selecting BESS suppliers?
2. How does the regulatory and policy landscape regulate BESS and is it conducive for investment in BESS?
3. What is the most sensible operational approach for an investor, and why?
4. Which market mechanisms can BESS participate in, and which revenue streams can be generated? Is participation in multiple markets (revenue stacking) possible?

Glossary

Ancillary Services

Ancillary services refer to specialized functions that help maintain grid stability and reliability. These services include frequency regulation, voltage control, reserves and black start capabilities. Ancillary services are essential for ensuring the uninterrupted supply of electricity. They help manage fluctuations in power demand and supply, prevent grid disturbances and support the integration of renewable energy sources, ultimately safeguarding the reliability and quality of electrical services **[4]**.

Types of frequency regulation (control reserves) in Europe:

- *Frequency Containment Reserve (FCR)* - Primary frequency response
  FCR must be available within 30 seconds. It is one of the first control reserve types to be deployed when the grid frequency deviates from the 50Hz target frequency. FCR is used to compensate for fluctuations in grid frequency in the short term and is activated automatically and across Europe **[2]**.
- *automatic Frequency Restoration Reserve (aFRR)* - Secondary reserve
  aFRR is used to relieve FCR that has been deployed, and it must be activated within five minutes. Activation takes place through a fully automated call-up by the TSO in whose control area the deviation in the system frequency has been registered **[2]**.
- *manual Frequency Restoration Reserve (mFRR)* - Tertiary reserve
  mFRR is used to relieve deployed aFRR and, in addition, to available aFRR to remedy more severe imbalances in system frequency. Activation takes place within 12.5 minutes for a period of at least 15 minutes after a manual decision to activate by the TSOs **[2]**.

Balancing market

These are crucial for the operation of electricity systems. They ensure that supply and demand are balanced in real-time. Balancing services are provided by market participants that can quickly adjust their output (generation or consumption) in response to signals from the system operator. The system operator uses these services to balance the system in real-time, ensuring the stability and reliability of the power supply **[1]**.

Capacity market

Implemented in some countries to ensure that enough generation capacity is available to meet peak demand. These markets provide payments to generators for being available to produce electricity, regardless of whether they are generating **[1]**.

Cap & Floor

A revenue model that sets both minimum (floor) and maximum (cap) earnings, limiting downside risk and upside potential.

Energy Arbitrage

The practice of buying electricity when prices are low and selling it when prices are high to profit from the price difference **[1]**.

Energy-Only Market

A power market (like ERCOT or NEM) that compensates generators solely for electricity sold, without separate capacity payments.

Fixed Tolling Agreement

A long-term contract where a BESS owner receives a fixed payment from an Optimizer, who takes on the market risk and reward.

Floor Price

A contract structure guaranteeing the BESS owner a minimum income, while still allowing for some participation in market upside.

Frequency Control Ancillary Services (FCAS)

Fast-acting services in markets like Australia that help maintain grid frequency by quickly charging or discharging batteries.

Fully Merchant Model

A high-risk setup where the BESS earns revenue entirely from market operations, with no guaranteed income.

Market Volatility

Rapid and unpredictable changes in electricity prices, which can create high-risk, high-reward opportunities for BESS.

Optimizer

A third-party entity that manages the operation and market participation of a BESS to maximize its profitability.

Real-Time Algorithmic Trading

The use of automated systems to decide when to charge or discharge a BESS based on real-time market conditions.

Resource Adequacy (RA)

A form of capacity payment in California, ensuring energy providers have sufficient resources to meet demand during peak periods.

Revenue Stacking

The strategy of combining multiple revenue sources (e.g., arbitrage, ancillary services) to maximize total income.

Trading-as-a-Service (TaaS)

A specialized service where third parties optimize the trading strategies for BESS owners, especially in fully merchant models.

Wholesale market

Where electricity is bought and sold in bulk. It includes the day-ahead market, where electricity for the next day is traded, and the intraday market, which allows for closer to real-time trading to adjust positions **[1]**.

Exhibits

Exhibit 1 : Growth of BESS market (2023 - 2030), McKinsey & Company' **[10]**

View the exhibit at Enabling renewable energy with battery energy storage systems | McKinsey

https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/enabling-renewable-energy-with-battery-energy-storage-systems

Exhibit 2 : Comparative Regulatory and Policy Matrix for BESS Deployment in Texas, California, UK, Germany, Australia and Chile

Regulatory Factor	Texas (ERCOT)	California (CAISO)	UK	Germany	Australia	Chile
Market Participation (Wholesale & Ancillary Markets)	✔ Fully Open	✔ Open but CAISO curtailment risk	✔ Open, strong ancillary markets	⚠ Open but with prequalification requirements	✔ Open, good revenue stacking	⚠ Partial access, evolving
Revenue Stacking (Multiple Revenue Sources)	✔ Strong	✔ Strong	✔ Strong	⚠ Moderate	✔ Moderate	⚠ Developing
Grid Fees & Double Charging (Extra Grid Costs?)	✔ No double charging	✔ No double charging	✔ No double charging	✔ No double charging for in-front-of-the-meter BESS	✔ No double charging	✖ Double charging issues
Incentives & Subsidies (Government Support?)	✔ IRA 30% tax credit	✔ SGIP + IRA	⚠ CfD & Capacity Market	⚠ EU Green Deal. Uncertainty due to new government (CDU/SPD)	⚠ State-Level Incentives	✖ Minimal incentives
Permitting & Interconnection (Approval & Grid Connection Speed)	✔ Fast	⚠ Medium (some delays)	⚠ Moderate (improving)	✖ Slow (bureaucratic hurdles)	⚠ Moderate (varies by state)	✖ Slow (grid bottlenecks)
Utility Ownership Restrictions (Can utilities own BESS?)	✖ Restricted	✖ Restricted	✔ Allowed	✔ Allowed	✔ Allowed	✔ Allowed

Exhibit 3 : Trading process schematics/activities of a BESS asset

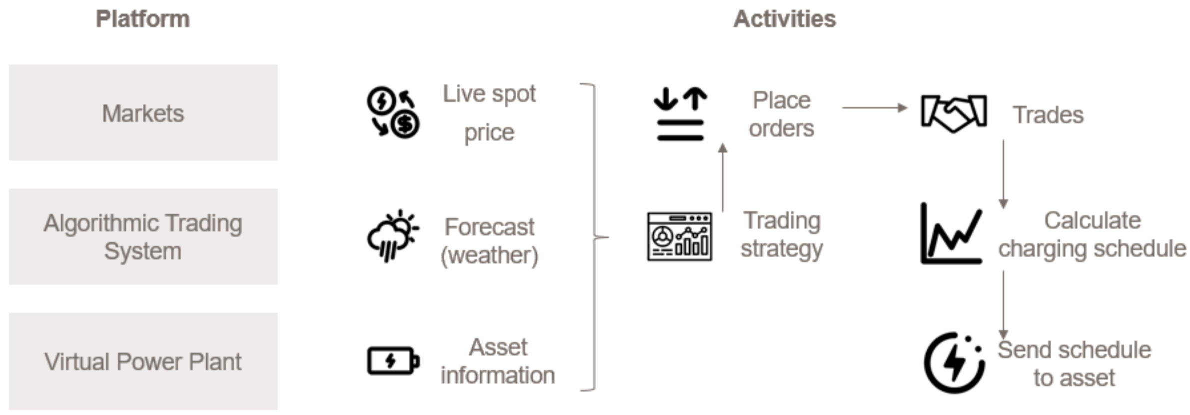

Exhibit 4 : Trading process schematics/activities of a BESS asset **[8]**

Categories	Characteristics	Examples
Utility trading desks	• Established trading capabilities for BESS • Wide range of (algorithmic) trading strategies • Managing their own flex portfolio (source of conflict of interest) • Can offer fixed revenue of floor structures to an asset owner because of their strong balance sheet	Engie Statkraft EDF Vattenfall
Energy traders	• Established trading capabilities • Often less mature BESS optimization capabilities • Stronger balance sheet allowing them to provide floor prices	Shell BP Vitol Trafigura
Trading as a Service providers	• Focus on data science, machine learning and AI optimization and analysis techniques • Proprietary trading algorithms allow a BESS owner to tap into the various markets, so called trading as a service providers • Small balance sheets so not able to provide guaranteed revenues or floor prices.	Entrix Habitat Enspired Yuso

Exhibit 5 : Characteristics and optimization potential of possible BESS operational contractual set-ups **[7]**

	Tolling	Floor without cap	Floor with cap	Fully Merchant
Downside protection	full	Floor	Floor	none
Upside potential	none	Unlimited	Capped	Unlimited
Risk profile	low	medium	medium	High
Fee	included	share from total revenue	Revenue share up to cap	share from total revenue

View the associated graph of asset owner revenue as a function of optimization performance here: BESS revenue models: tolling, floor & fully merchant

https://hub.enspired-trading.com/blog/bess-revenue-models-toll-floor-fully-merchant

Exhibit 6 : Technical & Financial Assumptions for a 100MW/200MWh BESS

Capex (Capital Expenditure): Approximately **€400–500 per kWh** of installed capacity. This equates to roughly **€80–100 million total** upfront cost for a 100 MW/200 MWh system, consistent with recent estimates (e.g. ~€800k per MW for 2h duration). Regional cost variations and IRA incentives (in the US) can lower this (Lazard reports post-IRA LCOS as low as $124/MWh for 4h systems).

Opex (Operational Expenditure): Around **2–3% of Capex per year** for fixed operation & maintenance. This covers routine maintenance, warranty management, software, and staffing.

Efficiency & Degradation: Round-trip efficiency ~85–90%, typical for Li-ion BESS. **Capacity degradation ~2% per year**, assuming one full cycle per day; augmentation (adding new modules) may be planned to maintain usable capacity over a 15-year project life.

Financing Structure: A base-case project finance assumes **70% debt / 30% equity** for contracted revenue models (lower risk) and a higher equity share (or mezzanine financing) for merchant projects (due to revenue uncertainty). Cost of capital ranges widely: e.g. ~6–8% weighted average cost for contracted or hedged projects vs **12%+ for merchant** projects (a high-risk investor demands higher returns).

Lifetime & Cycling: 15-year nominal life, targeting ~4,000–5,000 full cycles before major replacement.

Exhibit 7 : Example monthly revenue change for a UK 2-hour BESS (Sept to Oct 2024) **[11]**

> Lower Capacity Market earnings (red, −£3k) were offset by higher ancillary service and trading revenues (green, +£12k combined), resulting in a net increase to £58k/MW-year in October.

View the exhibit here: GB Battery energy storage revenues decreased by 12% in November 2024 - Research

https://modoenergy.com/research/battery-energy-storage-revenues-gb-benchmark-november-2024-balancing-mechanism

Exhibit 8 : Estimated annual revenue of a 1MW/1MWh BESS in Germany **[12]**

> Estimated annual revenue for a 1 MW/1 MWh BESS in Germany from FCR (blue line) vs spot market arbitrage (green line), 2019–2023. Revenues rose dramatically in 2022 (peak of ~€180k/MW-year) due to high power prices and volatility, then fell in 2023 as conditions normalized and FCR prices declined. By 2023, arbitrage (green) nearly matched FCR revenue as battery competition caused FCR profitability to erode.

View the exhibit here: Revenue Potential for Battery Storage Systems on the Power Market - Current Developments - Energy BrainBlog

https://blog.energybrainpool.com/en/revenue-potential-for-battery-storage-systems-on-the-power-market-current-developments/

Exhibit 9 : Revenue Streams and indicative revenue potential for BESS

Market	Primary Revenue Streams	Annual Revenue Potential (per MW, in EUR)
UK	Wholesale trading (day-ahead, intraday) Fast frequency response (DC, DR) Balancing Mechanism & Reserve Capacity Market Payments	~ 100 – 170 k€ in volatile years ~ 70 – 100 k€ in steadier conditions
Australia (NEM)	Energy arbitrage (solar shift) FCAS (Regulation & Contingency incl. Very Fast) Offtake contracts (e.g. SIPS, PPA)	~€60k–120k average (post-2020 entrants) (First movers >€180k in 2018; future 4h proj. ~€160k)
Texas (ERCOT)	Real-time energy arbitrage (scarcity pricing) Ancillary services (Reg Up/Down, Responsive Reserve, Fast Reserve) (Future: Performance credits)	~€140k–170k in 2023 (Average ~$70k in H1 2024; huge upside in extreme events, e.g. >€300k/MW in Aug 2023)
California (CAISO)	Energy arbitrage (day-ahead & real-time "duck curve") Regulation & reserve ancillary services Resource Adequacy (capacity contracts)	~€90k–130k (with RA contract, e.g. $78k market + $50k RA) (Market-only: ~€70k in 2023; high year ~€100k)
Germany	Wholesale arbitrage (intraday, day-a-head) FCR (Frequency Containment Reserve) - primary reserve	~€80k–120k in 2022–23 (mix of FCR + trading) (Peak ~€180k in 2022; 2023 down to ~€80k)

	aFRR (automatic Frequency Restoration Reserve) - secondary reserve (Future: EU-wide reserve markets)	
Chile	Energy arbitrage (solar overgeneration to evening peak) Capacity payments (under new law) Ancillary services (frequency, spinning reserve) Tolling/PPA contracts with offtake	~€50k–100k (est. merchant arbitrage initially) (+ future capacity payment ~€30k–60k per MW if implemented)

Exhibit 10 : Example of supplier evaluation matrix

Category	Sub-Criteria	Weight (%)	Score (1-5)	Weighted Score
Technical Considerations (40%)	Energy Density	5%		
	Augmentation & Scalability	5%		
	Performance (Availability, Efficiency, Degradation)	10%		
Price Evaluation (25%)	CAPEX	25%		
	OPEX	15%		
	LCOS	5%		
Commercial Conditions (15%)	Warranty & Guarantees	5%		
	LTSAs conditions	5%		
	Contractual Flexibility	5%		
Additional Factors (10%)	Reputation & Track Record	4%		

	Research & Innovation	3%		
	Sustainability & ESG	3%		
Total Score		**100%**		**X / 5**

Exhibit 11 : Example of a basic BESS supplier screening (Pass/Fail) criteria

Criteria	Requirement	Pass / Fail
Battery Chemistry	Must align with project requirements	✅ / ❌
Safety & Compliance	Must meet IEC, UL, IEEE and other applicable standards	✅ / ❌
Scope	EPC, Battery Container supply or BESS solution provider / integrator	

Bibliography

[1] Alexa Capital - Investing in Energy Storage Report
https://www.alexa-capital.com/media/2062/alexa-capital-investing-in-energy-storage-report-may-2024.pdf

[2] Definition of Control Reserves
https://www.transnetbw.de/en/energy-market/ancillary-services/regelreserve

[3] PowerFlex - Battery Storage Incentives by State
https://www.powerflex.com/blog/battery-storage-incentives-by-state

[4]
https://www.gridx.ai/knowledge/ancillary-services#:~:text=Ancillary%20services%20refer%20to%20specialized,the%20uninterrupted%20supply%20of%20electricity.

[5] Morgan Lewis - US Energy Storage Policy Roadmap
https://www.morganlewis.com/pubs/2024/03/state-by-state-a-roadmap-through-the-current-us-energy-storage-policy-landscape

[6] California Public Utilities Commission - SGIP Program
https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/self-generation-incentive-program/participating-in-self-generation-incentive-program-sgip

[7] BESS revenue models: tolling, floor & fully merchant
https://hub.enspired-trading.com/blog/bess-revenue-models-toll-floor-fully-merchant

[8] European BESS offtake & financing – state of play
https://hub.enspired-trading.com/blog/bess-revenue-models-toll-floor-fully-merchant

[9] Tackling merchant risk – A deep dive into Europe grid-scale energy storage contracted revenue
https://timera-energy.com/blog/european-bess-offtake-financing-state-of-play/

[10] Enabling renewable energy with battery energy storage systems
https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/enabling-renewable-energy-with-battery-energy-storage-systems

[11] Modo Energy**:** GB Battery energy storage revenues
https://modoenergy.com/research/battery-energy-storage-revenues-gb-benchmark-november-2024-balancing-mechanism

[12] Revenue Potential for Battery Storage Systems on the Power Market – Current Developments
https://blog.energybrainpool.com/en/revenue-potential-for-battery-storage-systems-on-the-power-market-current-developments/