Unlocking the potential – Navigating key considerations in battery energy storage systems

Developing a successful business case

October 2023
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Introduction

In today's evolving energy landscape with the increasing integration of renewable energy sources (RES) and the phase-out of fossil-fuel-powered facilities, battery energy storage systems (BESS) have emerged as a key area for investment. The significant shift towards sustainable energy solutions has created the foundation for BESS to thrive, with the prospect of substantial growth in investment over the coming decades.

Battery energy storage systems possess the ability to participate in multiple revenue streams and, at the same time, stack some of them to optimise revenue generation. Not only do BESS support grid stability and provide balance in increasingly volatile and congested systems, but they also capitalise on the volatility in short-term energy markets, leveraging their capabilities to participate in energy arbitrage.¹

Optimising earnings through strategic stacking of revenue streams requires investors to develop cross-market optimisation strategies whilst taking regulatory compliance and market dynamics in consideration. Furthermore, the trend of increasing BESS duration is here to stay and will likely grow to capture more value in trading spreads or to secure capacity remuneration in markets where it is a viable option. The changes in revenue opportunities across the expected lifespan of BESS underscore the importance of carefully considering assumptions regarding the warranty and insurance conditions to utilise the system in a way that allows tapping into the emerging market opportunities. For that, flexibility is increasingly becoming a must-have.

As technological advancements continue to drive down the costs associated with longer-duration energy storage systems, BESS is well-positioned to directly compete with other energy storage and generation assets. This shift in the energy sector not only extends BESS' reach, but also further diversifies its revenue streams allowing BESS to compete effectively in an increasing number of ancillary services.

The costs associated with deploying and operating BESS must be balanced with the specific use cases underpinning the business case. For example, the planned utilisation impacts both the need for capital and operational expenditure. A misalignment between the expected deployment (revenue streams) and assumptions on costs represents a risk to the profitability of a project. Investors and project developers particularly need to account for the largest components of capital expenditure, such as buying the system and land rights, as well as the operational expenses for running the system, such as grid fees, optimisation costs and operations and maintenance. Lastly, planning for the end of the BESS' life during the construction phase can potentially improve the business case through updated assumptions regarding the residual value of the system, as well as risks or opportunities associated with recycling.

We anticipate that new technology will likely make BESS cheaper and more appealing to investors year by year, quite visible by 2024 to late 2020s. This may affect the strategy around investment

¹ Although this paper does not delve into applications of renewable energy integration—transmission system operator (TSO)-level investments or its synergies and value provided to EV charging infrastructure, such opportunities can potentially further extend the investment options. For example, BESS can prevent the need for expensive grid upgrades when providing extra capacity to EV charging infrastructure or can provide optimal fleet charging if co-located with a BESS + PV system. Our whitepaper on electrifying fleets discusses the constraints in this space and potential value of onsite flexibility (See Electrifying fleets – challenges, opportunities and considerations – CRA, 2023)
opportunities and timing. The influence of technological advancements on the business case in terms of battery lifespan can be material, as illustrated by the difference in number of cycles between Lithium-ion batteries and Lithium-iron-phosphate batteries, making technology choices a pivotal consideration for investors.

In addition to revenue and cost considerations, other elements to consider when assessing investment prospects include:

- understanding of how the evolving regulatory framework may affect revenue stream accessibility;
- exposure and sensitivity to shifts within the market environment and system conditions;
- approach to augmentations and system adjustments to optimise the long-term value and potentially benefit from future technological advancements; and
- operational risks that could affect performance and reliability and mitigation strategies in place.

Developing models that simulate scenarios and options of revenue stacking, market prices and utilisation, while maintaining warranty conditions or stress testing is a must. This should be done under different assumptions on regulation, market, competitive dynamics and technological advancements to provide insights into potential developments. Understanding the potential value at risk enables better informed risk-management decisions and development of mitigation strategies, where risks are material. CRA leverages an Energy Storage Operations model alongside fundamental analysis and market and regulatory review to assess risks and recommend mitigation strategies.

In the following whitepaper, we delve into a comprehensive exploration of the revenue streams, cost dynamics and other critical considerations that are integral to creating a robust BESS business case, offering valuable insights for investors seeking to leverage the full potential of this dynamic and evolving sector.
**Revenue streams**

BESS, with its ability to store cheap energy over time and to supply it when needed (and renumerated), can provide diverse income sources for investors. Table 1 below illustrates the main BESS revenue streams, focusing on capacity provision, ancillary services and energy arbitrage.²

Table 1: Most relevant revenue streams and value stack³,⁴

<table>
<thead>
<tr>
<th>Value stack</th>
<th>Revenue streams for BESS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Firm capacity</strong>&lt;br&gt; <em>Not available in every jurisdiction</em></td>
<td>Capacity markets offer a dependable revenue source for capacity providers, leveraging a financial basis for future investments. In return for this revenue, providers must ensure the availability of energy during system stress periods, with potential penalties for failure to meet these obligations. BESS can participate in the capacity market, earning revenue by providing the necessary capacity.</td>
</tr>
<tr>
<td><strong>Ancillary services</strong></td>
<td>Maintaining grid stability requires an immediate response to frequency fluctuations, whether they rise or fall. BESS systems can generate revenue by providing these services.</td>
</tr>
<tr>
<td>Frequency</td>
<td>During peak demand periods additional power resources, known as reserve services, will be needed to ensure grid reliability. BESS can act quickly to inject energy to make up the shortfall.</td>
</tr>
<tr>
<td>Reserve</td>
<td>Balancing services are essential for maintaining the stability of the electrical grid. They involve adjusting the supply of electricity in real-time to match the constantly changing demand. BESS can generate revenue by participating in balancing services as the systems respond rapidly to fluctuations in electricity supply and demand, helping to balance the grid.</td>
</tr>
<tr>
<td>Balancing</td>
<td>Energy arbitrage involves charging BESS batteries when low-cost electricity is available and discharging stored energy when demand and prices are high. This can be executed in day-ahead (DA) markets or intraday trading, offering revenue opportunities for BESS.</td>
</tr>
</tbody>
</table>

Ancillary services related to frequency response and balancing may have different names and definitions across markets. Frequency response services refer to any services that can be provided by market participants in connection with unexpected changes to the transmission system frequency, involving providing or consuming additional energy.⁵ For example, in the UK,

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² While BESS has additional applications like integrating renewable energy sources and deferring transmission and distribution investments, these are not covered in this paper’s scope. We also do not delve into collocation and hybrid setups in this paper. However, it is worth mentioning that BESS can be leveraged to improve value of renewable project by improving capture rates or preventing curtailment and that BESS can also be utilised in tandem with electric vehicle (EV) charging infrastructure where other business cases become attractive, such as the use of BESS to avoid expensive upgrades of grid connections when greater capacity is required for fleet infrastructure or utilising a co-located BESS alongside a PV asset to charge a fleet of EV’s.
³ Nor-Cal Controls, “BESS Benefits: How Battery Energy Storage Systems Support the Grid”, October 2021
⁴ National Grid ESO, “What is the Capacity Market?”
⁵ European Association for Storage of Energy (EASE), “Ancillary Services”, August 2021
this is known as firm frequency response or Dynamic X, while other markets such as Germany categorise it into primary, secondary and tertiary control power. Other markets, in turn, may refer to these as automated frequency restoration reserves and manual frequency restoration reserves. In all cases, when referring to frequency response services, we encompass all the variations above. Balancing services, on the other hand, restore the balance between supply and demand on the grid through mechanisms separate from frequency response services. This may happen through explicit market arrangements such as the Balancing Market in Ireland, or implicitly through passive balancing such as the case in the Netherlands; a model driven by price signals, meaning that sometimes it is cheaper to self-regulate, whereas in other instances it may be cheaper to pay an external party for restoring balance to the transmission system.

**Firm capacity**

Capacity markets, where available, can play a pivotal role in securing long-term revenue streams for newly established battery energy Storage Systems. They offer opportunities for BESS to secure multi-year contracts for their capacity in various regions, including the UK, Belgium, and Italy. However, as the recent capacity auction results in the UK have shown, BESS have become insensitive to capacity prices, showing that capacity remuneration does not constitute the main driver of life-time value. Rather, it incentivises investment through revenues secured ahead of deployment to build a business case, as has recently been acknowledged and thus implemented in Belgium. Other markets with existing or planned capacity markets can be seen in Figure 1 below.

**Figure 1: Capacity renumeration mechanisms in Western Europe**

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6 Ampiron connects, “Balancing Capacity in Germany”
7 Next Kraftwerke, “What is aFRR (automatic frequency restoration reserve) and how does it work?”
9 DNV, “Battery Energy Storage Systems in the Netherlands”
10 Timera Energy, “A tour of European capacity markets”, February 2020
11 Timera Energy, “Implications of a surge in UK capacity prices”, February 2023
12 Elia Group, “Capacity Remuneration Mechanism”
As the integration of RES progresses, the role of BESS in providing firm capacity will likely increase through shifting generation across time. Part of this increase will come from co-located plants, but standalone projects could benefit from this as well, as for example in the UK where more than 600 MW of capacity have been awarded to BESS in the 2023-24 capacity auction, many of which were standalone systems held by investors. The increasing derating factors compared to T-1 see Figure 2, only 50% of BESS that secured contracts were one-hour duration systems, and 42% were two-hour duration. In total, 627 MW of capacity was awarded to battery storage, an increase of 63% from 385 MW in the year prior. Moreover, the T-4 auction awarded 1,247 MW to BESS at a record price of 63£/kW/y through (usually) 15-year contracts.

**Figure 2: Derating factors for duration-limited storage in UK; February 2023 CM auction**

BESS investors should prioritise longer-duration systems and recognise how capacity remuneration incentivises investment through revenues secured ahead of deployment to build a business case.

**Ancillary services**

Providing ancillary services to the grid is another way investors can capitalise on BESS. Table 2 below illustrates various options for ancillary services that may be accessible to BESS; the actual availability depends on the market. For example, certain services, such as congestion relief, may be absent in numerous markets. Additionally, some services, such as black start, are in the early stages of development with BESS being preferred to their diesel generator counterparts; only in 2021 did Siemens Energy win the first black-start battery storage project for power generation in

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13 Energy Storage News, “UK T-1 Capacity Market battery storage contract awards up 63% to 627MW”, February 2023

14 T-1 and T-4 refer to 1 year before delivery and 4 years before delivery, respectively.
Notably, frequency response services often reach saturation levels as markets mature, while balancing services continue to offer opportunities for BESS.\textsuperscript{17}

Table 2: Ancillary services open to BESS (non-exhaustive)

<table>
<thead>
<tr>
<th>Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency response reserve</td>
<td>Activated when system frequency deviates from its target frequency; either increases or decreases power on system.</td>
</tr>
<tr>
<td>Balancing services</td>
<td>Through balancing services, transmission system operators (TSOs) balance supply and demand on a second-by-second basis to ensure the system remains balanced throughout.</td>
</tr>
<tr>
<td>Voltage management</td>
<td>Consists of the provision or absorption of reactive power to ensure stable voltage across entire system.</td>
</tr>
<tr>
<td>System inertia</td>
<td>Aids in limiting or slowing down large frequency changes; generally provided through moving parts but also possible for BESS through virtual inertia.\textsuperscript{18}</td>
</tr>
<tr>
<td>Reserve power</td>
<td>Provision of power during unforeseen changes to demand or supply; not as quick as frequency response but provided in larger volumes.\textsuperscript{19}</td>
</tr>
<tr>
<td>Black start</td>
<td>Ability to start grid networks or generators without external energy sources.\textsuperscript{20}</td>
</tr>
<tr>
<td>Congestion relief</td>
<td>Also called Transmission &amp; Distribution investment deferral; BESS can provide congestion relief by re-dispatching or absorbing excess electricity; remunerated in some markets such as GOPACS in Netherlands.\textsuperscript{21}</td>
</tr>
<tr>
<td>New ancillary services</td>
<td>Consists of variety of new services emerging in some European countries, such as fast frequency response or dynamic reactive response.\textsuperscript{22}</td>
</tr>
</tbody>
</table>

**Frequency response reserves**

BESS are highly suitable for frequency response services due to their ability to ramp up almost immediately, which may even lead to premium rewards for their speed, as exemplified in Ireland.

\textsuperscript{15} Siemens Energy, “Siemens Energy wins its first black-start battery storage project for power generation in the U.S.”, January 2021  
\textsuperscript{16} National Grid ESO, “First GB voltage management project goes live in world-first for independent business”, May 2021  
\textsuperscript{17} Timera Energy, “Structural Transition in the UK battery revenue stack”, October 2022  
\textsuperscript{18} Energy Storage News, “Upgrade at Tesla Batery project demonstrates project feasibility of once in a century energy transformation for Australia”, July 2022  
\textsuperscript{19} Drax, “What are ancillary services”  
\textsuperscript{20} Hjalmarsson, Thomas, Bostrom, “Service stacking using energy storage systems for grid applications – A review”, April 2023  
\textsuperscript{21} GOPACS, “Congestion Management Products”  
\textsuperscript{22} European Association for Storage of Energy (EASE), “Ancillary Services”, August 2021
where premiums could triple the prices per megawatt per hour.\(^{23}\) Furthermore, according to Modo Energy, over 90% of battery revenues in 2022 have come from frequency-response services, dominated by firm-frequency response, dynamic containment, dynamic regulation and dynamic moderation.\(^{24}\) However, participation in these services is subject to highly regulated environments, often limiting the contracting of multiple frequency response services. This may change as new frequency restoration services are introduced, such as a new suite of dynamic services in the UK which can be stacked with each other.

**Balancing services**

Balancing services are a value pool that BESS can leverage; typically, these services enable the real-time balancing of the system by bridging the gap between market-scheduled supply and actual system demand. This is done by determining the balancing prices, which are then paid by the units responsible for causing system imbalance to the units restoring balance. The structure and legal option to optimise for these markets, however, varies drastically from country to country, causing the viability of this revenue stream to vary accordingly. In some countries, such as Germany, any speculations on imbalance are prohibited, and if observed, result in fines or exclusion from the market participation. Where available, then, as markets for ancillary services become saturated, balancing markets can play an increasingly important role in generating revenues from a BESS.\(^{25}\) Contributing to system balance allows BESS operators to optimise revenues close to real-time, through mechanisms such as the balancing mechanism in the UK or passive balancing in the Netherlands. Moreover, imbalance prices tend to be highly volatile, so participating in system balancing offers an additional opportunity for arbitrage. Similar to trading in intraday and day-ahead (DA) markets, however, careful optimisation around the impacts of charge cycles on battery health is required.

**Energy arbitrage**

Another revenue stream accessible to BESS is energy arbitrage (also known as energy time-shifting), which in most cases is available to BESS with minimal barriers to entry. System characteristics required to participate in the wholesale markets are only impacted by the product granularity (i.e., in markets where DA products are one hour, the ability to trade single-hourly blocks is required). The underlying rationale is to buy (charge) energy when prices are low (e.g., at night, excess generation from RES) and sell (discharge) when prices are high during peak times in regular market transactions. In terms of near-term optimisation, the intraday market provides an opportunity to optimise system utilisation close to real-time. This, however, requires capabilities to manage risk and optimise bidding. The increasingly volatile markets promise wider price spreads and hence arbitrage opportunities.

Given the intermittent nature of renewables, their increased penetration usually leads to growth in market price volatility, as the supply and demand may mismatch more often, making arbitrage more attractive. Other factors that determine the capturable spread for BESS are market tightness and the duration over which the battery can store energy.

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\(^{23}\) Economic Consulting Associates (ECA), “Fast & furious: fast frequency response services as the key to rev up battery investments”, November 2021

\(^{24}\) Modo Energy, “Mandatory Frequency Response: the other frequency response market”, June 2022

\(^{25}\) Timera Energy, “Are battery revenues falling in 2023”, March 2023
Arbitrage in DA markets also relies on the capture of price spreads. Depending on price formation dynamics and regulation, price spreads on the DA market may be lower than on the intraday market. However, bidding into DA market is often less complex and requires less real-time optimisation and speed, which may also reduce risks and costs of bidding.

Long-term outlook

As markets mature, wholesale arbitrage is expected to take over from ancillary services as the main revenue stream due to the relatively low volumes in demand at auctions and hence quick saturation. For instance, in the UK, one-hour duration storage now dominates the market for frequency-response services. An increasing influx of storage capacity has caused saturation within the existing ancillary markets, prompting re-evaluation of revenue streams. Insights from industry experts have identified a notable decrease in revenue derived from ancillary services within the UK over the past year, for example dynamic containment (L) fell from 15£/MW/h across summer 2022 to 4.5-5 £/MW/h. Although this trend shows that revenues for storage from ancillary services are declining, new avenues of potential services are emerging, such as New Dynamic Services (DC/DM/DR) replacing dynamic firm frequency response (FFR). Therefore, we expect a degree of evolution in ancillary services with arising new opportunities for selected bidders who would be best positioned to bid, at least in selected markets, depending on their generation mix and grid congestion. However, over the longer term, it may be reasonable to expect battery investment to be driven primarily by wholesale arbitrage opportunities.

Currently, BESS are well suited for short-duration frequency response services (primary and secondary) due to their energy-limited nature. As the technology progresses and prices decrease, they may prove suitable to provide long-duration (tertiary) response services with discharge durations of greater than one hour, such as manual frequency restoration reserves and replacement reserves, which may require multiple hours of capacity at times. However, these are not to be seen as potential revenue drivers, but rather, additional opportunities to diversify the revenue stream and contribute to system optimisation.

Revenue stacking

As outlined above, BESS can provide a variety of services to the power system as well as leverage its flexibility to generate value in short-term wholesale markets. These revenue streams are often not mutually exclusive and represent an opportunity to combine (some of) them to increase the total revenue generated by the storage system. This bundling of applications and revenue streams is referred to as value stacking, revenue stacking or cross-market optimisation; Modo Energy refers to it as “the ability to earn revenue simultaneously from multiple sources using the same capacity.”

The ability to generate revenues from various streams simultaneously within the energy market is growing in significance. A cross-market optimisation strategy would enable investors to tap into multiple revenue streams, delivering optimised value through selective participation. The selection

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26 Timera Energy, “Battery investors confront revenue shift in 2023”, February 2023  
27 Timera Energy, “GB Batteries confront ancillary saturation”, October 2022  
28 National Grid ESO, “New Dynamic Servies”  
29 Modo Energy, “Understanding BESS Revenue Stacking”, August 2022
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is a dynamic process, and the combination differs from period to period. Enspired\textsuperscript{30} outlines two optimisation approaches: horizontal and vertical. The horizontal approach treats the entire day as a single block, allocating a portion of capacity to various markets, such as wholesale and frequency containment reserve (FCR). In contrast, the vertical approach divides capacity into smaller granular, time-bound blocks (e.g., four-hour slots), enabling more detailed optimisation across a range of market options. To allow for cross-market optimisation,\textsuperscript{30} revenue streams need to be considered in light of current regulations. For instance, in the UK, simultaneous participation in FFR and wholesale arbitrage, or other dynamic frequency services, is not permitted due to the potential risk of being unable to meet delivery requirements. This is a notable risk, and typically stems from inadequate SoE management or technical challenges with pushing the BESS with cross-market participation and optimisation.

Revenue stacking is essential to maximise revenue from BESS, however cross-market optimisation strategies need to be evaluated against regulations, considering market dynamics and technical limitations of the system.

Warranty and insurance considerations

On top of a commercial strategy to underpin revenue generation, it is essential to account for battery degradation and related warranty and insurance conditions. Each manufacturer specifies terms of warranty specific to the product or component. These terms can limit the scope of cross-market optimisation, impacting the options for revenue diversification, optimisation and profits. Therefore, already in the design and component procurement phase, investors should consider potential revenue streams and utilisation scenarios and select a system that allows to tap into those streams without voiding the warranties. Warranties are relevant to the bankability of a project as they impact choices regarding other component supplies, commissioning process, operational and maintenance services etc.\textsuperscript{31}

In general, there are two types of warranties relevant to batteries: product warranty and performance warranty. The product warranty includes terms stipulating that the battery or system has been manufactured, handled, and installed properly. The performance warranty guarantees that the battery will perform at a certain capacity for a certain length of time.\textsuperscript{32}

The performance warranty is relevant to operations and commercial value generation. Performance warranties, as well as conditions (or constraints to the warranty), differ by producer and vary by battery chemistries. They can include metrics such as defined (lifetime) number of years or cycles, throughput, end-of-warranty capacity rating or minimum availability.

\textsuperscript{30} Clean Horizon Consulting, “How to optimise battery operation in the European markets”, March 2023
\textsuperscript{31} DNV, “Energy Storage Capacity Warranties: Beyond the Fine Print”
\textsuperscript{32} TWAICE, “De-risk your BESS projects by keeping track of warranty condition”, September 2022
To be able to fall back on the guarantees, specific conditions (i.e., ‘warranty constraints’) need to be met. Those can include maintaining a certain temperature range (e.g., 20°-25°) or required average State of Charge (SoC) or C-rate, cycling frequency (per day, per year) or charging rate and depth of discharge. Some warranties also include scalability restrictions or specifications that the initial battery system cannot be expanded. This is useful to consider when including augmentation as part of the project business case.

It is important to note that not all parts of the storage system will have the same warranties. For example, inverters often have separate warranties from the batteries. Aligning requirements and warranties relevant to the entire project/investment is essential to mitigate financial risk related to failures and loss of warranty.

Increasingly, some BESS providers offer more flexible warranty terms that put control and economic tradeoffs in the hands of the project owner or operator, leaving it up to the “owner or operator to decide, within a range of allowable operational strategies, how to operate the BESS to maximize revenue.”31 This can be particularly useful in cases when changes in market conditions present opportunities to generate higher revenues by utilising the battery system more aggressively, e.g., by increasing number of cycles. As the BESS market matures, such type of flexible warranties may increase, and will need to be linked to business case assumptions and modelling to identify optimum strategy.

**Costs**

Upfront costs for BESS have been decreasing steadily (except for 2022 due to Lithium-carbonate prices rising from supply chain problems during the COVID-19 pandemic and partially mis-forecasted EV adoption33), thus broadening the potential for longer-duration BESS investment opportunities. This trend is expected to continue going forward, as illustrated in Figure 3, unlocking new opportunities for investors to diversify their revenue stream and tap into new markets, particularly from 2024 onwards, which is when investments in four-hour duration storage are forecasted to become viable.34

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33 Energy Storage News, “BESS cost base has gone up 25% year-on-year, says Wärtsilä”, July, 2022
34 Timera Energy, “What battery durations are investable”, May 2020
Technological advancements have been a major driver in the decrease in costs for BESS, while simultaneously, markets are recognising the value rapid-response storage systems have to offer. As expertise in developing and managing storage assets evolves, installation costs have also been decreasing. As the BESS deployment gathers momentum across various markets, investors are confronted with choices relating to the optimal system configuration for their business needs, with an emphasis on battery power and storage duration, which bear a significant impact on the revenue streams available to investors.

The costs associated with BESS are expected to decline with technological advancements, unlocking new opportunities for investors to tap into markets, particularly from 2024 onwards.

Breakdown of capital expenditure
Capital expenditure (CAPEX) of BESS can be broken down into five buckets, as shown in Table 3. As costs vary with both power and duration of the system – which in turn vary with the use case of the BESS – the contribution of each component to CAPEX is dependent on the desired use of the battery.

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35 Aurora, “Long term electricity storage in GB”, February 2022
36 NREL, “Utility-Scale Battery Storage”, July 2022
The most significant component of CAPEX are the system costs, which are mainly driven by the chosen battery chemistry, power and storage duration. As Lithium-ion batteries are currently the most prevalent battery chemistry, the following illustrations will be based on that technology – although similar dynamics can be expected from other types of batteries as well.36

Figure 4 and Figure 5 illustrate the impact of storage duration on both cost per kilowatt per hour and costs per kilowatt. For BESS focussing on arbitrage, duration is key in capturing wider price-spreads, making ≥2-hour systems the desirable choice going forward. With longer durations, the costs-per-kilowatt-hour decline, signifying a reduction in the costs-per-unit sold on wholesale markets.

Since storage duration bears no impact on the electrical power equipment, the main driver behind this trend is the decreasing costs of supporting equipment and construction, such as inverters, balance-of-system components and developer costs and profits.36 On the other hand, prices per kilowatt increase considerably with duration. As such, systems focussing on the provision of ancillary services are generally short-duration systems as they can provide peak capacity during short-system stress events, which combined with quick response times and moderate investment costs provides a reliable stream of income until ancillary markets saturate.

### Table 3: Composition of CAPEX

<table>
<thead>
<tr>
<th>CAPEX category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Battery cabinets – Battery modules and Balance-of-system components. Management systems – Battery-management software; Control and monitoring system. Balance-of-system components (containers, power-management system etc.).</td>
</tr>
<tr>
<td>Connection</td>
<td>Connection fee. Connection equipment (switchgear, inverter, transformer etc.). Energy-management system.</td>
</tr>
<tr>
<td>Construction</td>
<td>Engineering, procurement and construction (EPC) &amp; developer profits. Labour and equipment costs.</td>
</tr>
<tr>
<td>Land</td>
<td>Costs associated with acquisition/leasing of land varies by case but may prove difficult in certain instances.</td>
</tr>
<tr>
<td>Other</td>
<td>Permits, regulatory, tax.</td>
</tr>
</tbody>
</table>
Aside from the system characteristics, BoS components and the battery management system contribute to the system costs. BoS components may include the container, switchgears, heating, ventilation and air conditioning systems. However, as these technologies are relatively mature, the only cost-optimisation potential from BoS stems from the degree of customisation (i.e., the inclusion of any components beyond what is included with the system\(^\text{37}\)), although some learning effects can be expected in the future. Key drivers in reducing costs of battery systems include advancements in battery technology as well as production capacity.

**Connection and construction costs**

The other components of CAPEX are the costs incurred by construction and connecting the BESS to the grid, among other expenses. In particular, they consist of the power equipment, controls and communication systems, system integration and any applicable connection fees depending on

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geography. Relative to battery cells, these systems are fairly mature technologies, thus won’t be the main drivers of cost reductions going forward, although costs per kilowatt per hour incurred by controls and communications and connection equipment decrease considerably with the energy capacity of the battery.\(^3\)\(^8\) Construction costs mainly consist of the developer’s costs, EPC costs and labour and equipment costs. Across battery sizes, these costs remain largely constant. However, with increasing expertise and standardisation across the industry stemming from increasing construction activity around BESS and increased competition, costs here are expected to decrease.

**Land acquisition and long-term lease**

Land acquisition is a distinct category with costs highly dependent on specific site characteristics. Legal expenses may increase considerably if the chosen site is on land where ownership splits multiple owners, potentially delaying construction. Moreover, site characteristics may require additional land to be purchased for the construction of infrastructure necessary to operate the BESS, such as access to roads, especially in remote locations. Notably, while land acquisition does not contribute significantly to the overall system costs, it presents administrative, legal and planning challenges during development. Location choice becomes more important in markets where locational benefits have the potential to contribute to the revenue stack, such as congestion relief in the Netherlands. Furthermore, as BESS deployment evolves, prices for desirable sites are anticipated to rise, mirroring the trend observed in the UK. In such instances, complications associated with land acquisition may impose significant constraints on revenue streams and project timelines, potentially forcing developers to opt for suboptimal sites and forego additional value as BESS scales.\(^3\)\(^9\)

An alternative option to acquiring land would be to lease the land, particularly as these storage systems have a smaller footprint compared to other renewables. This option can become more financially beneficial as it lowers the initial CAPEX requirement for investors. Additionally, BESS investors can explore synergies with other technologies like solar or wind power in terms of land sharing.\(^4\)\(^0\)

**Other costs**

Lastly, other remaining capital expenses stem from taxes, permits and regulatory costs. Generally, these do not bear a large impact on costs. Rather, the regulatory environment determines whether projects are possible at all, bearing either a prohibitively large or minor impact on overall costs, depending on geography and legislation.

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38 NREL, “Utility-Scale Battery Storage”, July 2022
39 Timera Energy, “Surveying the European battery investment landscape”, August 2022
40 Stephens Crown “Battery Storage – offering new opportunities”, March 2023
Breakdown of operational expenditure

Similar to CAPEX, operational expenditure (OPEX) varies with the use cases of the battery and can be broken down into variable and fixed costs, each with multiple subcategories, as per Table 4.

Table 4: Components of OPEX

<table>
<thead>
<tr>
<th>OPEX category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable costs</td>
<td></td>
</tr>
<tr>
<td>Operations and maintenance (O&amp;M)</td>
<td>Includes general, scheduled and unscheduled maintenance; varying degrees of operations services depending on provider.</td>
</tr>
<tr>
<td>Replacement of parts</td>
<td>Replacement of consumable parts.</td>
</tr>
<tr>
<td>Grid fees</td>
<td>Fees paid to transmission and distribution system operators; vary by market and location.</td>
</tr>
<tr>
<td>Electricity costs</td>
<td>Cost of electricity used for charging and operating.</td>
</tr>
<tr>
<td>Optimiser costs</td>
<td>Costs incurred by optimiser.</td>
</tr>
<tr>
<td>Fixed costs</td>
<td></td>
</tr>
<tr>
<td>Operating labour and monitoring services</td>
<td>Labour for day-to-day operation of BESS; may come as part of purchase or through optimiser/O&amp;M (e.g., Fluence).</td>
</tr>
<tr>
<td>Property payments</td>
<td>Property taxes, land lease if applicable.</td>
</tr>
<tr>
<td>Insurance</td>
<td>Insurance for BESS.</td>
</tr>
<tr>
<td>Administrative</td>
<td>Administrative fees and labour.</td>
</tr>
</tbody>
</table>

Variable costs

Generally, the category bearing the largest impact on OPEX is the operations and maintenance cost. As with CAPEX, these variable costs vary according to the battery’s use case. The operations and maintenance cost component for BESS is primarily determined by how intensively the batteries are used, rather than their duration and capacity. In other words, the extension and frequency of charging cycles, as well as the investors’ chosen strategy, will dictate the level of maintenance required. These factors also impact the replacement of parts that wear out over time as well as battery health over time.\(^{41}\) Again, the more intense the use of the battery, the more likely the replacement of consumable parts becomes, driving up the cost of OPEX. Employing remote monitoring, predictive maintenance systems and long-term service agreements could potentially mitigate these rises in OPEX costs, safeguarding investors’ business cases.

Secondly, grid fees are a crucial factor in determining the viability of the business case underpinning the investment. These fees generally consist of payments to the transmission system operator and distribution system operator, depending on the location of the BESS. These vary widely across markets, with the least favourable tariff structures focussing on peak capacity, as is the case in the Netherlands.\(^{42}\) This puts BESS at a disadvantage as their use is defined by short-

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\(^{41}\) Energy Storage News, “Every charge cycle counts when it comes to battery degradation”, September 2019

term, high-powered charging instead of continuous use. Moreover, in markets where energy storage is not separately defined, BESS risk being charged twice for using the grid both when charging and discharging energy, effectively breaking the business case for standalone systems, as is the case in the Netherlands.

Thirdly, electricity costs for BESS consist mainly of the cost for electricity used to charge and the associated efficiency losses. The approach for BESS charging is to charge during low-price periods, i.e., during high renewable output periods. Moreover, these costs depend on wider market conditions as well as the round-trip efficiency of the batteries, determining how much electricity is lost in the conversion process. However, electricity costs are not a defining factor for the business case. Instead, investors should focus on the price spread available in energy markets, as costs are expected to be recouped through arbitrage, thus making price volatility the defining factor in terms of electricity costs.

Lastly, in terms of variable costs, costs are incurred by the optimiser. Usually, optimisers are involved based on a revenue sharing agreement. As such, absolute costs incurred by optimisers increase with the financial performance of the BESS asset but remain at a fixed share. However, in addition to revenue sharing, the choice in optimiser also impacts battery life, as well as access to financing in more mature markets, thus indirectly further impacting costs.

**Fixed costs**

Fixed costs, consisting of operating labour, property payments, insurance and administrative costs, generally tend to be lower than variable costs. Operating labour may come as part of the purchase of the BESS, or it may be provided through optimisers or O&M providers. Generally, there are varying models of providing operating labour, ranging from full outsourcing to training and hiring own staff and depending on the degree of independence and risk desired by the investor. Overall, operating labour is a much lower expense compared to the insurance and property payments. In a similar vein, administrative costs are also relatively low.

Property payments consist of property taxes and land lease payments, where applicable. As markets mature, costs incurred from the location may increase as competition around desirable sites increases and the integration of locational services advances. In general these are expected to contribute little to the overall costs of operating a BESS, although it is worth highlighting that this also depends on the composition of land ownership and other legal requirements. Lastly, insurance fees depend mostly on the use case of the BESS; with more intense use, the risk of frequent or sooner breakdowns increases, thus increasing insurance premiums. In other words, standalone systems opting for an arbitrage-based strategy may incur higher insurance fees than ones opting for the provision of ancillary services. For chemistries other than Lithium-ion, insurance fees may vary as well.

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43 Timera Energy, “EU battery investment”, April 2023
End-of-life costs

Although end-of-life costs are not the most important driver, investors should still prioritise addressing end-of-life considerations during the construction phase. However, not all jurisdictions require decommissioning to be planned before operation commences, in part owing to the industry being relatively young and BESS being highly componentised. Many of the components in use, though, can be recycled, off-setting decommissioning costs and contributing to the system's overall sustainability.44 In particular, the components that can be recycled include the battery cells, metals both within the cells and from the construction among other components.45 Key considerations to be made when planning decommissioning are:44,46,

- The project acreage, which tends to increase with capacity.
- The type of facility the BESS is enclosed in.
- The weight of the components, which bears an impact on transportation costs.
- Regulatory requirements and potential future requirements around land-use considerations, with focus on above-ground and underground components.
- Recycling and disposal alternatives.

Careful operational planning provides an opportunity to minimise costs by incorporating potential revenues from recycling the battery plant as well as accurate accounting of all costs involved in constructing and operating a BESS, providing a deeper understanding of the business case underpinning the investment.

Other key considerations supporting the business case

Beyond revenue and cost considerations, other factors must be considered when evaluating investment opportunities. These include understanding the impact of the evolving regulatory landscape on the accessibility of revenue streams, shifts in market dynamics and system conditions, the need for modifications and upgrades to the BESS throughout its lifetime, technological advancements and operational risks, including the performance and reliability of the BESS.

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44 DNV, “5 things to consider for your battery project decommissioning”, October 2023
Regulatory environment considerations

Regulation significantly influences BESS profitability by determining accessibility to revenue streams. In Europe, Germany and the UK are leaders in BESS deployment, with Germany boasting 1.3 GWh of installed capacity\(^\text{47}\) and the UK installing capacity of 789 MWh with a further 4.3 GWh under construction in 2022 alone\(^\text{48}\). A key consideration for Germany and the UK is the favourable regulatory environment for battery energy storage systems. For example, in Germany there is a special tariff regime for energy storage facilities where there is a 20-year exemption of the transmission tariff component for facilities built between 2011 and 2026.\(^\text{49}\) Within the UK, government policies such as the et-zero strategy and the ten-point plan have helped create a favourable market for energy storage and unlock private investments.\(^\text{50}\) Other countries, such as Belgium and the Netherlands, have recently started to narrow the gap to market leaders. Italy, on the other hand, is considered the next emerging opportunity market, characterised by an increased target for installations and benefiting from a capacity auction that is now in place\(^\text{51}\). As the regulatory dynamics differ across Europe, it is crucial that investors navigate the different regulatory regimes, particularly when assessing potential business case opportunities and which market to enter.

Changes in the market and system conditions

Several current and future considerations should be understood when reviewing system conditions that influence the revenue potential for BESS. Key aspects such as the generation mix of power sources (e.g., level of renewable energy penetration or availability of dispatchable generation), the presence of alternative storage solutions (e.g., pumped hydro), grid congestion and plans for grid upgrades as well as the competitive saturation within the market, including existing projects as well as the planned pipeline (e.g., planning applications and grid connection requests). As the market and system conditions continuously change, when investors must review these assumptions to understand the risks and sensitivities associated with potential changes when assessing a business case or considering investment. It is imperative that investors can stress test scenarios in line with the market changes. This proactive approach ensures a level of confidence in the realisation of expected revenues and allows for early mitigation strategies to address any adverse developments in the markets that can impact the business case.

BESS configuration - modification and upgrade considerations

Considerations around system augmentation and upgrades play an important role in the business case for battery investors. As battery energy storage projects age, depending on their functionality and how they have been operating, their capacity and efficiency decrease.\(^\text{52}\) One approach to account for this would be reducing the service offered by the project in line with degrading energy capacity. This approach, however, may not be ideal for all projects, as it could limit the revenue potential and operational capabilities in the long run. The second option is to overbuild or oversize the initial battery capacity to deliver the intended revenue stack throughout the project's lifetime.

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\(^{47}\) Eco-Stor Speichermonitor Database, https://speichermonitor.eco-stor.de

\(^{48}\) Energy Storage News, “800MWh of utility-scale energy storage capacity added in the UK during 2022”, February 2023


\(^{50}\) Pacific Green, “Why the UK is a leader in battery energy storage”, September 2022

\(^{51}\) Energy Storage News, “Italy’s grid-scale energy storage market: a sleeping dragon”, June 2023

\(^{52}\) Burns McDonnel, “Battery Energy Storage Augmentation: Key project considerations”
This approach requires a higher initial CAPEX but eliminates future challenges associated with the degradation. 53 Another option is augmentation, wherein existing batteries are supplemented with additional new ones as needed throughout the system’s lifetime to maintain project performance or increase the capacity of the existing resource. 54 This can result in a lower initial CAPEX, allowing investors to pay for the capacity they need while reducing technological lock-in risk with obsolete battery technologies. Additionally, system compatibility with future batteries and supply-chain constraints may become an issue. The final option is to repower, replacing all onsite batteries, and potentially the balance of the plant as well. This can address obsolescence issues and align the energy storage system with the latest technologies but would otherwise prove costly. The choice between the approaches depends on several factors, and at its core is an interplay of trade-offs between upfront costs, technical complexity and different options available; understanding this interplay is essential for investors when they are building their business case. 55

Developments in technology

In recent years, battery energy storage systems have made significant technological advancements, specifically driven by innovations in materials, chemistries, and manufacturing processes. Moreover, battery companies are constantly experimenting to find chemistries that are cheaper, denser, lighter and more powerful. 56 Lithium-ion batteries, traditionally used for short-term grid storage, now face competition from emerging technologies such as flow batteries, particularly suited for long-term energy applications. 57 For instance, in the California, ESS is set to deploy iron-flow, long-duration energy storage systems capable of delivering up to 200 MW/2 GWh of power to Sacramento. This marks a significant milestone as it represents the first commissioning of iron-flow batteries in California, showcasing the expanding landscape of energy storage possibilities. 58 Lithium-ion batteries also face increasing competition from Lithium-iron-phosphate batteries as the improved lifespan impacts the number of cycles that can be expected throughout the lifetime, substantially improving their business case. 59 As these technologies continue to mature, their implications for investors will become more significant. Not only will operational efficiencies be significantly enhanced, but new and compelling investment opportunities will likely emerge, presenting a transformative shift in the energy storage sector.

Operational risks, including performance & reliability considerations

BESS exhibit variations in performance and reliability which can impact potential returns for investors business cases. To make informed decisions, investors must assess the technical aspect of BESS, including performance, reliability and the mitigation of operational risks. While opting for low-cost options may initially seem attractive, compromising on quality and reliability can lead to significant long-term risks and expenses. Therefore, striking the right balance between cost and performance is essential to ensure an optimal return on investment and the long-term viability of BESS business case. This is particularly crucial as operational risks (e.g., fires caused by

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54 Morgan Lewis, “Key Considerations for Utility-Scale Energy Storage Procurements”, March 2023
55 Everoze, “Battery Sizing: Oversize, Augment, Reduce or Repower?”, September 2017
56 Saft, “Three battery technologies that could power the future”, October 2023
59 Li Time, “Lifepo4 Vs Lithium-Ion Batteries: Which One Should You Choose?”, April 2023
thermal runaway or control system failures, environmental impacts and cybersecurity vulnerabilities) require careful attention as they can affect the long-term viability of the business case.\textsuperscript{60,61,62} To further mitigate risks and enhance control, investors can leverage advanced technologies, such as artificial intelligence analytics, predictive maintenance and smart bidding, to enable data-driven decisions and bring confidence in battery health.\textsuperscript{63} Additionally, insurance premiums can offer valuable insights into the quality and risk profile of a battery energy storage system,\textsuperscript{64-66} with insurers considering factors including overall design, components used and safety measures when determining premiums.\textsuperscript{66} Ultimately, investors need to properly account for technical considerations as they are pivotal in safeguarding investments and optimising returns.

Understanding other impacts that underpin and influence the business case is essential to ensure the long-term success of the BESS. It is particularly important to understand the regulatory environment, the shifts in market dynamics and system conditions, the need for modifications and upgrades, the technological advancements and the operational risks.

**Conclusion**

The business case for BESS needs to consider the interplay between revenue streams and costs, factoring in the changing nature of the markets and the likely need for flexibility and adjustment in terms of operations, market participation or even technical setup.

Revenue stacking, shifting between market opportunities and advanced bidding strategies will grow in importance. An increase in sophistication can influence the costs and required capabilities leading to make-or-buy-decisions around services and know how.

On the cost front, declining BESS costs are unlocking new investment opportunities. Achieving the right balance between technology and economic considerations is crucial for viable business cases. As the system and land-acquisition costs represent the most substantial CAPEX components, alternative options for investors should be considered, such as leasing the land. Moreover, investors could look at creating synergies with previously built renewable systems, allowing them a head start in creating a business case for BESS. Additionally, end-of-life considerations should not be overlooked, as incorporating potential recycling revenues can minimise costs during the construction phase.

\textsuperscript{60} Marsh Commercial, “Battery energy storage systems fire risks explained”, February 2021
\textsuperscript{61} National Fire Protection Association, “Battery Energy Storage Hazards and Failure Modes”, December 2021
\textsuperscript{62} Actuarial Post, “Invisible cyber risks identified to energy storage market”
\textsuperscript{63} TWAICE, “Data-driven batteries built on indisputable facts”
\textsuperscript{64} Hajeforosh, Bollen, Ahmad, “Reliability Aspects of Battery Energy Storage in the Power Grid”, November 2020
\textsuperscript{65} Energy Storage News, “Data-driven insurance for batteries: An unsung hero of the green energy transition”, April 2022
\textsuperscript{66} Marsh Commercial, “Battery energy storage systems fire risks explained”, February 2021
Developing models that simulate scenarios and options of revenue stacking under different assumptions is important. Such models should account for potential operational constraints related to the BESS and relevant warranty requirements. In the early stages of investment decisions, the modelling tool could help with decision making regarding the system design, ensuring the resulting configuration aligns with the intended business model and revenue generation. Subsequently, the model could also assist in the ongoing assessment of market participation strategies and potential adjustments, including forecasting the impacts on revenues and system degradation when modifying strategies, responding to new revenue opportunities or adapting to evolving market dynamics and value shifts, such as heightened volatility or increased cycling requirements to fulfil contracted services, or the introduction of multi-market participation opportunities.

An effective model should possess the ability to evaluate multiple options individually and in combination. It should offer the necessary level of detail, aligning with the granularity of bidding within the actual market(s), which may vary based on country and market-specific characteristics. Furthermore, the model should account for operational and warranty constraints, encompassing factors such as the number of cycles per day per year, state of charge thresholds, charging rates, round-trip efficiency, storage capacity, recommended depth of discharge/charge and ramp rate, among others. These constraint limits should be adjustable, allowing for the modelling of trade-offs as needed.

Throughout the lifespan of a BESS project, it is probable that multiple models will be utilised as markets or regulation evolves, ranging from the initial project planning phase, through investment decision making, market optimiser selection and into operations. Investors should recognise the fundamental capabilities of these models and leverage the valuable insights they can provide at different stages of the BESS project's lifecycle.

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