CHALMERS
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The Development of Large-Scale BESS in Sweden

A Technology Monitoring Analysis of Trends, Drivers, and Barriers

Master's thesis in Industrial Ecology

PONTUS CRAFOORD
IDA GRUNDBERG

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS

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Supervisor: Chunshuo Ge, Department of Technology Management and Economics
Examiner: Björn Sandén, Department of Technology Management and Economics

Master's Thesis 2026
Department of Technology Management and Economics
Division of Environmental Systems Analysis
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: AI-generated by Gemini. Visualisation showing BESS surrounded by renewable energy resources.

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Abstract

The rapid transition of the Swedish power system, driven by electrification and an increasing share of variable renewable energy, has created the need for flexibility resources. This has led to a significant expansion of large-scale Battery Energy Storage Systems (BESS). The aim of this thesis is to map the current BESS market landscape in Sweden and to analyze the underlying drivers, structural barriers, and future trajectories.

The study applies a mixed-methods approach, combining a quantitative mapping of Swedish BESS projects exceeding 1 MW with a qualitative analysis based on 19 semi-structured interviews with key industry actors, including project developers, system operators (DSO/TSO) and authorities. The findings are interpreted using three complementary theoretical lenses, the Technology Life Cycle and S-curve, the Multi-Level Perspective, and the Technological Innovation System framework, applied as conceptual tools rather than as a structuring framework.

The results show that the market has grown rapidly to approximately 1,3 GW of confirmed operational capacity, initially driven by exceptional profitability in the FCR-D ancillary service market. Following its saturation, the market has recalibrated toward mFRR participation, energy arbitrage, and value-stacking across multiple revenue streams. New application niches are also emerging in co-location with renewables, industrial peak shaving, and local grid flexibility, alongside a technical shift toward longer storage durations.

The key barriers identified are predominantly institutional: regulatory ambiguity around BESS classification, a fragmented DSO landscape with inconsistent standards, opaque grid connection processes, and a misalignment between commercial incentives and broader systemic value. These constitute blocking mechanisms slowing the market's transition into a full growth phase. The thesis concludes that the future trajectory of Swedish BESS depends less on technical readiness than on whether the institutional landscape can adapt to match the pace and direction of market development.

Keywords: Battery Energy Storage System, BESS, Sweden, Ancillary Services, FCR-D, mFRR, Energy Storage, Grid Flexibility, Value-stacking, Technological Innovation System, Energy Transition

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Pontus Crafoord & Ida Grundberg, Gothenburg, June 2026

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

aFRR	automatic Frequency Restoration Reserve
BESS	Battery Energy Storage System
BRP	Balance Responsible Party
BSP	Balancing Service Provider
DSO	Distribution System Operator
Ei	Swedish Energy Markets Inspectorate
FCR-D	Frequency Containment Reserve - Disturbance
FCR-N	Frequency Containment Reserve - Normal
LFP	Lithium Iron Phosphate
mFRR	manual Frequency Restoration Reserve
MLP	Multi-Level Perspective
PPA	Power Purchase Agreement
RfG	Requirements for Generators
SVK	Svenska kraftnät
TIS	Technological Innovation System
TSO	Transmission System Operator

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1 Introduction

The transition towards a sustainable, fossil-free energy system is one of the defining challenges of the 21st century. Driven by the international commitments made under the Paris Agreement, proposed in 2015 (United Nations, n.d.), countries around the world are restructuring their energy systems to reduce greenhouse gas emissions, primarily through the large-scale deployment of renewable energy sources such as wind and solar power. However, this shift introduces a fundamental challenge. Unlike conventional power plants, renewable sources are variable and weather-dependent, making it increasingly difficult for power systems to maintain the continuous balance between electricity production and consumption that is required for stable operation.

Sweden is at the forefront of this transition. With ambitious national targets, including net-zero emissions by 2045 (Government Offices of Sweden, 2021) and a fully fossil-free electricity production by 2040 (Swedish Energy Agency, 2025a), Sweden is undergoing a rapid expansion of both renewable energy production and electricity demand, the latter driven largely by the electrification of industry and transport. At the same time, the decommissioning of several nuclear reactors has reduced the physical rotational inertia that historically stabilised the grid's frequency (Svenska Kraftnät, 2025c). The combined effect of these developments creates a growing need for flexibility resources, technologies and services that can rapidly respond to imbalances and help maintain the grid's required frequency of 50 Hz.

Battery Energy Storage Systems (BESS) have emerged as one of the most prominent technologies to meet this need. Around 2020, participation in the Swedish ancillary services market became highly profitable for battery owners, triggering a rapid influx of new market actors and a sharp expansion of installed large-scale BESS capacity, as will be elaborated in chapter 4. This rapid, market-driven growth has, however, taken place within an institutional and regulatory landscape that was not originally designed with battery storage in mind (Energimarknadsinspektionen, 2016; European Commission, 2016), raising questions about how the technology is classified, how it connects to the grid, and how it is expected to develop going forward.

As the initial profitability that catalysed this growth begins to shift, the future trajectory of the Swedish BESS market remains uncertain. It is unclear which revenue streams and applications will drive continued investment, what structural or regulatory barriers may slow this development, and how the market's expansion aligns with the broader needs of the Swedish power system. A comprehensive, up-to-date overview of the current market landscape, combined with the perspectives of the actors operating within it, is therefore needed to understand not only where the BESS market in Sweden stands today, but also where it is heading.

This thesis addresses this need by combining a quantitative mapping of large-scale BESS projects in Sweden with a qualitative analysis based on interviews with key industry actors, including project developers, system operators, and regulatory authorities. By examining the market's development, its underlying drivers and barriers, and its anticipated future trajectories, this study aims to contribute both an empirical foundation and an analytical understanding of how the Swedish BESS market is evolving.

1.1 Aim and Research Questions

This thesis aims to understand the current landscape, ongoing development, and the future trajectory of the Battery Energy Storage System (BESS) market in Sweden. To achieve this, a technology monitoring analysis is applied. The current market landscape is mapped by identifying the installed BESS sites and key market actors. Furthermore, the thesis aims to analyze the existing market drivers, challenges, and trends in order to explore the future growth and directionality of the Swedish BESS market based on interviews with industry professionals. Additionally, the thesis examines the data landscape by exploring which market actors possess relevant data and which type of data they hold.

To achieve this aim, four research questions are formulated to support the research and act as a guide throughout the study.

1. How large is the currently operational and future planned BESS capacity in Sweden?

2. What are the drivers and barriers behind the development of BESS?

3. Which trends can be seen in the market and what are the future characteristics of BESS?

4. How can data availability improve to facilitate technology monitoring of BESS market development?

1.2 Scope and Limitations

The study is delimited to operational and announced large-scale BESS in Sweden, with a power capacity of at least 1 MW. The research focuses specifically on utility-scale Lithium-ion battery systems and excludes household-scale battery storage, such as home solar integration or electric vehicle charging. The study focuses on the application of BESS, rather than the chemical or technical details of the batteries themselves. The only technical aspects considered are battery power capacity (MW), battery energy capacity (MWh) and the battery storage time (often denoted C-rate).

The study further investigates the data landscape by identifying which market actors possess data on BESS and what type of data they hold. The scope is limited to the existence and accessibility of such data, and does not extend to the technical dimensions used for data transmission between actors.

Regarding the data collection, the quantitative database is limited by the unstructured nature of its sources. Since it relies on news articles, press releases, and company websites, there is no standardised publication process to draw from, meaning projects that have not been publicly announced cannot be captured. Another limitation is that in multiple cases, assumptions were made on the C-rate when data was missing on either how many MW or MWh the BESS contained. While these assumptions were based on interview materials, they still introduce uncertainty, especially regarding future projects.

Finally, given the rapid pace of development in the Swedish BESS market, both the database and qualitative findings reflect a specific snapshot in time. The market picture may shift considerably before this thesis is published, which should be kept in mind when assessing the currency of the results.

2
Industrial Context

Building on the broader context introduced above, this chapter presents the structural and institutional conditions that frame the development of the Swedish BESS market. The chapter moves from a macro-level perspective on Sweden's energy transition and grid structure, to the specific mechanics of the national balancing markets and local flexibility needs, before defining the technological and regulatory parameters of BESS and the institutional context governing market actors. Together, these sections provide the necessary background to interpret the market dynamics analysed later in this thesis.

2.1 Sweden's Energy Transition and Climate Goals

Sweden has several long term climate goals, one of them is net-zero emissions of greenhouse gases in the atmosphere by 2045. The goal is a key component of Sweden's efforts to comply with the Paris Agreement (Government Offices of Sweden, 2021). To reach this target, domestic greenhouse gas emissions must be reduced by 85% compared to 1990 levels. The remaining 15% will be managed through supplementary measures, such as carbon capture and storage (CCS) and carbon sequestration in forests and land (Government Offices of Sweden, 2021).

Alongside the net-zero target, Sweden aims for 100% fossil-free electricity production by 2040. To support this, the Swedish parliament has established specific planning and delivery security goals for the power grid. These mandate that the electricity system must reliably deliver sufficient power where and when needed to enable widespread electrification and the green transition. Furthermore, unjustified obstacles in the electricity system must be removed to create the conditions for an efficient market that promotes competitive prices (Swedish Energy Agency, 2025a).

The ongoing electrification of the industrial and transport sectors will fundamentally alter national electricity demand. Currently, Sweden's annual electricity production stands at approximately 160 TWh, primarily sourced from hydropower (42.4 %), nuclear power (28 %), and wind power (25 %) (Svenska Kraftnät, 2026). However, driven by the overarching climate transition, this volume must expand significantly in the coming decades. Forecasts from Swedish Energy Agency (2024) project an increase to 194 TWh by 2030, while Vattenfall (2023) estimates that demand could reach up to 330 TWh by 2045.

The transition toward climate neutrality entails phasing out fossil fuels. Replacing these energy sources involves extensive electrification, which is projected to significantly increase the national electricity demand. To meet this demand sustainably, the electricity supply will increasingly rely on weather-dependent renewable energy sources. However, integrating a higher share of intermittent power generation necessitates energy storage systems. Energy storage serves to balance and optimize the power grid by absorbing excess electricity during periods of high renewable generation and discharging it when production drops or during peak loads (Svenska Kraftnät, 2025f). Consequently, the Swedish Energy Agency highlights batteries as a crucial component for reaching Sweden's climate goals, as they provide the system flexibility needed to facilitate the broader energy transition (Swedish Energy Agency, 2025b).

2.2 The Swedish Electricity Grid and Structural Challenges

The electricity grid in Sweden consists of transmission and distribution networks and international connections (Svenska Kraftnät, 2024). Svenska Kraftnät is the Transmission System Operator (TSO) of the transmission networks, which means that they are responsible to maintain balance and stability in the system as a whole. In order to deliver electricity, the grid needs to be in balance at all times, which means that the electricity supply must be equal to the electricity consumption. Svenska Kraftnät procure different support services to maintain the balance, this is explained further in the next section "balance services" (Svenska Kraftnät, 2025g). The distribution networks can be divided into two individual networks: regional and local. Those who are responsible for the distribution network are called Distribution System Operator (DSO), and they manage the operational security in their grids, managing voltage and overloads. In Sweden, approximately 170 DSOs exist, where each DSO has monopoly of their electricity network. However, Sweden has a deregulated electricity market, meaning that selling electricity is competitive and costumers have approximately 140 suppliers to choose from. The Swedish Markets Inspectorate (Ei) regulate the electricity network operations in Sweden, and monitor the electricity markets (Energimarknadsinspektionen, 2022).

The transmission network was fundamentally designed to transport electricity from northern Sweden, where large amounts of electricity are produced via hydro and wind power, to the southern part of Sweden, where the majority of the energy is consumed. However, the grid has a technical maximum capacity for how much electricity can be transferred at any given time. This transfer capacity is not static, it fluctuates continuously based on factors such as ongoing grid maintenance, outside temperature, the direction of electric flow and the balance between supply and demand (Swedish Energy Agency, 2026).

To manage transmissions limitations, Sweden was divided into four bidding zones in 2011, they are SE1 (Luleå), SE2 (Sundsvall), SE3 (Stockholm) and SE4 (Malmö).

This geographical division makes it clear where reinforcement in the grid is needed, or where local production of electricity needs to increase. The price of electricity in each bidding zone is determined by the intersection of supply, demand and the available transmission capacity between the zones. When the grid reaches its maximum transfer limit between two zones, a physical bottleneck occurs. Consequently, cheaper electricity from the north cannot reach the demand centers in the south, causing prices between the bidding zones to diverge. To optimize the existing infrastructure and manage these constraints, a new "flow-based capacity calculation" method was introduced in October 2024. This method enables a higher volume of electricity to be transferred through the Nordic grid while maintaining operational security (Swedish Energy Agency, 2026).

2.3 Flexibility and Ancillary Services

Sweden has a deregulated electricity market, which encourages competitive trading and diverse production (Swedish Energy Agency, 2026). However, as the national energy mix shifts towards a higher proportion of intermittent, weather-dependent power sources such as wind and solar, the grid requires much more active balancing to maintain its standard 50 Hz frequency (Svenska Kraftnät, 2025e). Different services will be explained below.

2.3.1 The Balancing Market and Ancillary Services

In the electricity system, there must be an exact balance between the production and consumption of electricity at every second, which corresponds to a grid frequency of exactly 50 Hertz (Hz). Svenska kraftnät is the authority responsible for maintaining this short-term balance in the Swedish power system. If more electricity is produced than is consumed, the frequency rises above 50 Hz; conversely, if more electricity is used than produced, the frequency drops below 50 Hz (Svenska Kraftnät, 2025e).

Historically, the Swedish power grid relied heavily on the massive rotating turbines in nuclear and hydropower plants to provide physical "rotational inertia" (*svängmassa*). This physical inertia acts as a natural shock absorber, resisting sudden changes in grid frequency. However, as older nuclear reactors have been decommissioned and the share of weather-dependent, non-synchronous power sources (like wind and solar) has increased, the total physical inertia in the grid has decreased (Svenska Kraftnät, 2025c). This loss of inertia means that grid frequency can drop much faster during disturbances, creating an acute system need for synthetic inertia and ultra-fast responding assets, such as battery storage, to rapidly inject power and stabilize the grid before traditional hydropower can react.

To manage this, Svenska kraftnät buys and sells electricity in real-time on the balancing market (balansmarknaden). This process involves up-regulation (raising the frequency when it is too low) and down-regulation (lowering the frequency when it is too high). These processes are achieved through ancillary services provided by power generation facilities, flexible electricity consumers, or energy storage systems.

Down-regulation is achieved by having electricity producers reduce their output or by having large consumers increase their electricity usage (Svenska Kraftnät, 2025a).

To continuously correct imbalances, Svenska kraftnät procures ancillary services (stödtjänster) and remedial actions from market actors (Svenska Kraftnät, 2025d). These services are primarily divided into different categories of reserves (Svenska Kraftnät, 2025g):

- Frequency Containment Reserves (FCR): These reserves stabilize the frequency. They are divided into FCR-N, which is used during normal operations, and FCR-D, which is used during sudden disturbances.
- Frequency Restoration Reserves (FRR): These reserves are used to restore the grid frequency back to 50 Hz, which in turn releases the activated FCR reserves so they are ready for new disturbances. FRR is divided into products that activate automatically (aFRR) and manually (mFRR).
- Fast Frequency Reserve (FFR): Unlike other ancillary services that are traded on daily markets, FFR is a rapid remedial action procured on an annual basis through longer contracts.

To participate in the ancillary services and balancing markets, market actors must operate within specific roles defined by the Swedish TSO, Svenska kraftnät. An actor providing balancing capacity or grid reserves must be registered as a Balancing Service Provider (BSP) (Svenska Kraftnät, 2025b). Furthermore, any physical balance deviation in the grid must be financially covered by a Balance Responsible Party (BRP), who takes on the financial responsibility for the planned inputs and outputs of electricity in a specific portfolio (Svenska Kraftnät, 2025b). Under current market regulations, a BSP must also hold the BRP status for the specific delivery point to deliver balancing services to the national grid (Svenska Kraftnät, 2025b). This structural alignment ensures that the physical activation of an asset, such as a BESS project, is correctly accounted for financially within the electricity market framework.

2.3.2 Local Grid Flexibility

At the local and regional grid levels, a critical relationship exists between physical grid capacity and operational flexibility. Grid capacity refers to the maximum amount of power the physical infrastructure can safely transport at any given moment. When this capacity is fully utilized during peak hours, local bottlenecks occur, which restricts new customers from connecting to the grid or prevents existing customers from expanding their operations. Instead of relying solely on time-consuming physical grid expansions to increase capacity, Distribution System Operators (DSOs) can utilize flexibility, the ability to dynamically adjust electricity consumption or production. By using flexibility resources to reduce grid loads during peak hours, DSOs can free up existing capacity. One practical application of this dynamic is the use of conditional agreements (villkorade avtal) (E.ON Energidistribution (elnät), 2025).

A conditional agreement allows a customer to connect to the grid much faster by utilizing unused grid capacity. However, this requires the customer to have the technical capability to actively control their power usage. If the grid experiences a bottleneck, such as during peak load on a cold winter day, the grid owner sends a signal, and the customer must reduce their power consumption or production down to a pre-agreed basic, guaranteed level (E.ON Energidistribution (elnät), 2025).

Beyond conditional agreements, regional DSOs are increasingly piloting "Local Flexibility Markets" to proactively manage grid constraints. These digital trading platforms allow grid operators to purchase flexibility services, such as temporary power reduction or battery discharging, directly from local actors during peak hours. Prominent examples of this development in Sweden include *Effekthandel Väst*, operated in the Gothenburg region to alleviate winter bottlenecks (Göteborg Energi, n.d.), and the *SWITCH* platform utilized by E.ON to manage regional capacity challenges (E.ON, n.d.). By participating in these emerging local markets, BESS operators can generate additional revenue streams while directly supporting the stability of the regional infrastructure.

2.3.3 Power Purchase Agreements

A Power Purchase Agreement (PPA) is a long-term electricity trading contract, typically spanning 10 to 20 years, established between a power producer (such as a wind farm) and an electricity buyer, which can be an industrial company, a large real estate owner, or an electricity trader (Svensk Vindenergi, 2021).

These agreements serve critical financial purposes for both parties involved. For the electricity buyer, a PPA provides a predictable electricity price and acts as a safeguard against future price shocks on the volatile electricity market. For the power producer, the agreement guarantees a steady, long-term revenue stream. This revenue security is often a fundamental prerequisite for securing bank financing to construct new renewable energy facilities (Svensk Vindenergi, 2021).

Furthermore, PPAs are utilized by companies to strengthen their sustainability profiles. The contracts can be structured in various ways, including fixed prices or variable prices. They can also be executed as physical PPAs, where electricity is delivered via the grid, or as financial (virtual) PPAs, which are purely financial agreements regulating price differences without the physical transfer of electricity between the specific parties (Svensk Vindenergi, 2021).

2.4 Battery Energy Storage Systems (BESS)

A BESS can function as both a load during charging and a generation asset during discharging, it offers significant operational flexibility to power systems (National Renewable Energy Laboratory (NREL), 2021).

In the context of national grid support, utility-scale BESS, often referred to as front-of-the-meter or grid-scale storage, typically ranges in capacity from several MWh up to hundreds of MWh (International Renewable Energy Agency (IRENA), 2019). Among available battery chemistries, lithium-ion (Li-ion) technology currently dominates the market due to its fast response times and declining costs (International Renewable Energy Agency (IRENA), 2019). Compared to conventional mechanical storage such as pumped hydropower, utility-scale BESS offers greater geographical and modular flexibility, enabling rapid deployment and efficient scaling near areas of grid congestion or flexibility needs (International Renewable Energy Agency (IRENA), 2019).

An essential technical metric of BESS is the C-rate, which defines the rate at which a battery is charged or discharged relative to its maximum energy capacity. The C-rate establishes the relationship between the system's maximum power output (measured in MW) and its total energy capacity (measured in MWh). For instance, a 10 MW / 10 MWh battery operates at a 1C rate, meaning it can discharge its maximum power for exactly one hour before depleting. These shorter-duration, high-power systems are typically optimized for rapid frequency regulation markets. As the market expands, systems with lower C-rates and longer durations are increasing (International Renewable Energy Agency (IRENA), 2019).

In practice, utility-scale BESS serves several distinct roles in the electricity system. Currently, the most prominent commercial application is the provision of ancillary services, specifically frequency regulation, by selling capacity on national balancing markets (Power Circle, 2020). Another core application is energy arbitrage, where the battery is charged when electricity prices are low and discharged when prices are high (Vattenfall, n.d.). Related to this, BESS can perform "peak shaving" to reduce maximum power peaks, which helps stabilize the electricity supply during periods of high demand (Power Circle, 2020; Vattenfall, n.d.). This combination of multi-purpose applications, often referred to as "value-stacking", is actively being adopted to support local and national grids; for instance, the energy company Stockholm Exergi is deploying large-scale battery parks specifically to relieve the strained local grid in the Stockholm region while simultaneously participating in these balancing markets (Stockholm Exergi, 2023).

BESS can also serve as a critical resilience asset by providing backup power during sudden grid failures, enabling a continuous electricity supply for sensitive operations (Vattenfall, n.d.). Finally, by storing energy during off-peak hours and discharging it locally when the grid is highly loaded, BESS can effectively relieve local grid capacity constraints and reduce the immediate need for expensive physical grid infrastructure investments (Power Circle, 2020).

2.4.1 Regulatory Classification of BESS

The integration of BESS into the European power grid is governed by specific network codes, primarily the Requirement for Generators (RfG) framework established by the European Commission. Originally designed to standardize grid connection requirements for traditional, synchronous power-generating modules, the RfG framework does not explicitly define distinct technical requirements for energy storage systems (European Commission, 2016). Because batteries can act as both a load when charging and a generator when discharging, their classification within traditional regulatory frameworks remains ambiguous. In Sweden, this regulatory structure generally results in BESS being legally classified as a production facility when injecting power into the grid. According to the unbundling principles in the Swedish Electricity Act (*Ellagen*), this classification restricts DSOs from owning and operating BESS for general market purposes, leaving the deployment primarily to independent developers (Energimarknadsinspektionen, 2016).

3
Theory and Method

This chapter presents the theoretical foundation and the methodological approach used to answer the research questions of this thesis. To effectively capture and interpret the complexity of the development of large-scale BESS in Sweden, this chapter is divided into two main parts.

The first part (Section 3.1) introduces three complementary theoretical frameworks: the Technology Life Cycle and S-curve, the Multi-Level Perspective (MLP), and the Technological Innovation System (TIS) framework. Rather than dictating a rigid structure for the study, these frameworks act as interpretive lenses that provide a conceptual vocabulary for understanding the systemic conditions, drivers, and barriers shaping the BESS market.

The second part (Section 3.2 and onwards) outlines the research design, which employs a Mixed Methods approach to capture both the physical deployment and the underlying market logic. This involves a quantitative mapping to establish a database of large-scale BESS projects in Sweden , complemented by a qualitative study based on 19 semi-structured interviews with key industry actors. Together, the theory and method provide the necessary tools to navigate the empirical findings and analyze the future trajectory of the Swedish BESS landscape.

3.1 Theoretical Frameworks

Understanding the development of large-scale BESS in Sweden requires more than a description of what has occurred, it also requires conceptual tools to interpret why things have developed as they have, and what conditions shape the trajectory going forward. In this thesis, three theoretical frameworks are identified as particularly relevant for this purpose: the Technology Life Cycle and S-curve, the Multi-Level Perspective (MLP), and the Technological Innovation System (TIS) framework. Rather than structuring the analysis around these frameworks, they are introduced here as interpretive lenses that can be brought to the thematic analysis that follows. The frameworks are not applied systematically or exhaustively, instead, selected concepts from each are presented as analytical tools to understand the sociotechnical system BESS is part of.

Technology Lifecycles and Developmental Trajectories

The diffusion of new technologies tends to follow a recognisable pattern: an early phase of experimentation and limited adoption, followed by a period of rapid growth, and eventually a maturing or saturation of a given market. It is typically represented as an S-shaped curve plotting cumulative adoption or performance against time. The central purpose of the S-curve is to visualise the rate of development or adoption across the lifecycle of a technology. It is also used as a tool for making informed assessments of where a technology stands in its development (Andersson & Jacobsson, 2000).

The idea that technology diffusion can be understood as a series of successive market segments, where each functions as a minor S-curve, has been established in prior innovation studies. Andersson and Jacobsson (2000) developed a methodology for monitoring emerging technologies by tracking dynamics across nursing markets, bridging markets, and eventual mass-market segments. Their framework emphasises that the development of a technology is usually not a single smooth curve but a series of transitions with its own dynamics.

A relevant refinement of this perspective comes from Taylor and Taylor (2012), who propose that a technology should be defined by the purpose for which it is used, rather than by its physical form or components. This is itself an analytical choice: it is equally valid to treat BESS as a single technology with one life cycle, but treating it as a set of application-specific systems allows us to capture a more differentiated picture of the Swedish BESS-market development. The same physical technology, deployed over different purposes, is then understood and analysed across separate life cycles. This means that a single technology can simultaneously occupy different stages of maturity depending on the market application in question, one application may be saturating while another is accelerating and a third remains embryonic, all at the same time. The idea of overlapping S-curves provides central insights into the dynamics of the Swedish BESS market, and how separate applications can be understood over time.

Niches and Accumulation of Market Momentum

The Multi-Level Perspective (MLP) is a framework for understanding how large-scale sociotechnical transitions occur (Geels, 2002). It distinguishes between three analytical levels: the niche, where radical new technologies are developed and tested; the regime, which represents the stable, dominant configuration of existing technology, institutions, rules and practices; and the landscape, which encompasses the slow-moving macro context of broader societal trends, policies and external pressures.

From this framework, one specific concept is central to this thesis: niche-cumulation. Geels (2002) describes how radical innovations do not break through to regime level in a single step, but through a trajectory of incremental changes. The technology is adopted in multiple successive applications where each builds on the knowledge developed in the previous one. As Geels (2002) writes, the breakthrough from niche to regime-level occurs gradually, "as radical innovations are used in subsequent application domains or market niches, i.e. a cumulation of niches". This accumulation of knowledge across niches provides the system the capacity to scale.

This process of niche-cumulation is closely related to the overlapping S-curves described above. Each niche represents an application context in which the technology gains a partial foothold, building technical confidence, actor networks, and institutional recognition that can be carried forward into the next niche. In the Swedish BESS context, this trajectory is visible in the successive emergence of application domains, from specific ancillary services to energy arbitrage to co-location and industrial integration, each building on the commercial and technical knowledge established in the preceding phase.

A related concept from Geels (2002) is hybridisation, whereby radical new technologies enter markets not by competing head-on with established systems, but by linking up with existing technologies to solve a specific bottleneck. This concept offers another useful lens for understanding how early BESS deployments found entry points in the Swedish electricity system.

Systemic Conditions for Market Development

The Technological Innovation System (TIS) framework analyses the performance of innovation systems for emerging technologies (Bergek et al., 2008). A system is understood as comprising actors, networks, and institutions that together either enable or constrain the development of the technology in focus. The framework identifies seven key processes (referred to as functions) through which a system generates the conditions for growth: knowledge development and diffusion, influence on the direction of search, entrepreneurial experimentation, market formation, legitimation, resource mobilisation, and development of positive externalities. These functions are introduced here as a conceptual background rather than an analytical checklist, however, they remain useful for interpreting the thematic analysis section.

Two specific concepts from the TIS framework are particularly relevant to this thesis. The first is the distinction between a formative phase and a growth phase. Bergek et al. (2008) characterise the formative phase by high uncertainty, low volumes, underdeveloped institutions, and weak self-reinforcing mechanisms. The growth phase, in contrast, is characterised by self-sustaining scaling, bridging markets, and increasing institutionalisation. Bergek et al. (2008) note that the performance of a function which appears weak may be entirely appropriate for a system in an earlier formative stage, meaning that what looks like underperformance must be evaluated against the developmental context rather than against an absolute standard. Determining the phase in which a technology currently operates is therefore an important step in contextualising its performance and trajectory.

The second key concept is that of blocking mechanisms: factors that hinder the development and progression from one phase to the next (Bergek et al., 2008). These can be internal or external to the system, arising either from weak functions within the system itself or from the broader institutional or regulatory context. Identifying such mechanisms is central in order to draw conclusions about what conditions need to change for the system to advance into a more self-sustaining trajectory.

How the Frameworks Relate

The three frameworks are not applied in parallel or exhaustively. They operate at different levels of abstraction and are drawn upon selectively according to where each offers the most insight. Together, they provide a set of conceptual tools for characterising both the current state of the Swedish BESS market and the conditions shaping its further development.

The S-curve and overlapping life cycle concepts, drawing on Andersson and Jacobsson (2000) and Taylor and Taylor (2012), address where BESS currently stands in its developmental trajectory and how different application segments can be at different stages simultaneously. The concept of niche-cumulation (Geels, 2002) addresses how momentum builds across successive application contexts and what that accumulation means for the technology's capacity to scale. The TIS concepts of formative and growth phases, and of blocking mechanisms (Bergek et al., 2008), address what systemic conditions are enabling or constraining the transition from the current phase to a more self-sustaining market.

3.2 Method and Research Approach

This thesis consists of two complementary methodological approaches, together forming a Mixed Methods research design (Creswell et al., 2006). The first is a quantitative mapping of large-scale BESS projects in Sweden, with the purpose of generating a novel and complete dataset on a project-based detail level. The second is a qualitative study based on semi-structured interviews with industry-connected actors, where the interviewees' interpretations, experiences, and assessments of the mechanisms behind the market are in focus. As argued by Creswell et al. (2006), integrating interpretive qualitative research in this manner extends the mixed methods framework by providing a deeper contextual understanding. Therefore, the data gathered through interviews serves as the primary foundation when examining the market landscape from the perspective of the actors operating within it. Together, these two parts form the empirical foundation of the analysis, which integrates both data streams thematically across the analytical section that follows.

Data collection and analysis were both conducted openly, without a predetermined theoretical framework, allowing themes to emerge from the empirical material. The theoretical frameworks presented in the preceding section were therefore not used to structure the data collection or guide the analytical process. Rather, they provide a conceptual vocabulary through which the findings can be read, offering tools for situating the empirical patterns within a broader understanding of how technologies develop and what conditions shape their trajectories.

The first step of the research process was to frame the problem and formulate research questions. As mentioned above, this was initially done by conducting an initial exploratory literature review to gain domain knowledge, but also by consulting with both the thesis supervisor and examiner as well as the commissioning supervisors from Energimyndigheten. This process yielded a preliminary description of the aim, scope, and research questions, which was continuously revised as the work progressed. The review further contributed with sufficient knowledge to navigate the Swedish BESS landscape, identify relevant data sources, and prepare for the interview phase. The subjects of interest were Swedish electricity market, ancillary service markets, grid regulation and structure, and existing studies on energy storage deployment in Sweden.

3.3 Data Collection

3.3.1 BESS Database

A central part of this thesis was to compile a structured dataset of operational and planned (announced or in construction) large-scale BESS projects in Sweden, defined here as projects with a power exceeding 1 MW. The starting point was an existing dataset of BESS projects compiled by the commissioning organisation covering the period up to 2022/2023. Each entry was first validated to confirm current operational status, and whether then-planned projects had since been realised. This validation process also led to the identification of additional projects not previously captured. The dataset was subsequently expanded through iterative online searches, navigation of developer websites, press releases, and publicly available project portfolios. Two supplementary datasets provided further cross-references: a 2023 BESS mapping published by Ny Teknik (von Schultz et al., 2024), and a mapping of European energy storage projects commissioned by Joint Research Centre (European Commission, 2026). Although both were incomplete or outdated at the time of use, they contributed additional projects and allowed for partial validity checks. Where data was unclear or missing, entries were flagged accordingly; uncertain project statuses were retained in the dataset with explicit notation.

Before data collection began, a set of relevant data categories was defined, resulting in a database. The key categories are summarised in Table 3.1 below.

Table 3.1: Key data categories in the BESS project database.

#	**Data categories**
1	Project name & location
2	Operator / developer
3	Project status (operational / announced / in construction / unconfirmed)
4	Year of commissioning (or expected year)
5	Installed power (MW)
6	Energy capacity (MWh)
7	Storage duration (MW/MWh ratio, i.e. C-rate)
8	Grid connection type & voltage level
9	Associated electricity production (e.g. PV, wind, hydro)
10	Primary purpose / use case
11	Co-location with industrial facility
12	Data source
13	Verification status / notes

3.3.2 Semi-structured Interviews

The study includes 19 semi-structured, in-depth interviews with actors representing a diverse range of actor categories and professional roles across the Swedish BESS ecosystem. Semi-structured interviews were chosen as the primary method since according to Adams (2015), this method is particularly well-suited for research requiring open-ended questions and follow-up queries. By employing a semi-structured format, interviewees were allowed to speak freely, ensuring that all predefined themes were covered while simultaneously enabling follow-up questions on relevant topics that arose organically during the conversation.

The distinct actor categories were BESS project developer, distribution system operators (DSOs), the transmission system operator (TSO), balance service provider (BSPs), electricity supplier, aggregators, and regulatory authorities.

Interviewees were identified through two complementary approaches: first, by summarising all organisations that appeared in the data collection phase; and second, by deliberately adding actor types not directly represented in the database, such as regulatory authorities, DSOs, and the TSO, to ensure a broad range of perspectives. Actors were categorised by their primary business role, and a purposive sampling approach was used to ensure representation across actor types and geographical areas. The full list of interviewees and their respective organisations are listed in Table 3.2 below.

Table 3.2: Overview of all interviews conducted, including organisation and actor type. **Interviews with Varberg Energi (number 11 and 13) were conducted together, however since they represent two different sides within the organisation they are separated in the analysis.*

#	Organisation	Name	Professional Role	Actor Type	Time [min]
1	Checkwatt	Erik Wallnér	Product Owner	Aggregator	90
2	Byhmgard	Fredrik Rosengren	Investor Relations	BESS Project Developer	60
3	Ellevio Energy Solutions	Dennis Bohm	Asset Owner	BESS Project Developer	60
4	Anonymized	Anonymized	Specialist, PV & Energy Storage	BESS Project Developer	60
5	Ingrid	Vincent Gliniewicz	Strategy Manager	BESS Project Developer, Optimizers	60
6	Paradisenergi	Johan Paradis	CTO	BESS Project Developer	90
7	Powerworks	Viktor Charpentier	CEO	BESS Project Developer	60
8	Falu Energi & Vatten	Oscar Willén & Gustav Öhberg	Grid Market Manager, Analyst	DSO	60
9	Göteborg Energi Elnät	Simon Siöstedt	Grid Capacity Manager	DSO	60
10	Jämtkraft AB	Johanna Renman	Development Engineer	BSP/BRP	40
11	Varberg Energi Elnät	Hans Ljungström	Head of Business Area	DSO	60*
12	Vattenfall	Magnus Berg	Portfolio Manager	BSP	60
13	Varberg Energi Elhandel	Jens Nordberg	Head of Energy Trading	Energy Supplier	60*
14	Uniper	Henrik Pagels	Operations Manager for Karlshamnsverket	Energy Industry	75
15	Vattenfall	Magnus Lövgren	Hydropower Specialist. Team Leader Asset Management	Energy Supplier	75
16	Energimarknads-inspektionen	Marielle Lahti	Expert	Supervisory Authority	40
17	Volvo Group	Staffan Rödjedal	Director Transport Industry Transition	Sustainability / Automotive	30
18	Svenska Kraftnät	Oscar Jonsson & Alicia Lööf		TSO	45
19	Energimyndigheten	Klara Bjerndal & Johan Harryson		Authority	45

An interview guide, see Appendix A, was developed to ensure all interviews contributed to answering the research questions. The guide covered four core themes: market drivers, challenges, trends and future outlook. A few interviews yielded supplementary information, such as the mechanism behind the frequency regulation markets, which were used for background understanding and not included in the analysis.

Interviewees were informed of the purpose and themes in advance. 15 interviews were conducted online via Teams, and three interviews were conducted in person. 16 of the 18 interviews were recorded and subsequently transcribed. The remaining two were documented through manual notes, as the interviewees did not consent to recording. The interviewees were primarily senior executives or employees with strategic insight into BESS operations, as seen in Table 3.2 above.

To ensure accuracy and secure consent, we shared the selected interview excerpts with each participant before finalizing the thesis. This step allowed them to review their quotes, suggest corrections, and explicitly approve the use of their data.

3.4 Data Analysis

3.4.1 Quantitative Analysis

Before the analysis, the database was reviewed and standardised to ensure consistency. In cases where only either MW or MWh data was available but not both, the missing value was estimated based on a capacity ratio assumption. For projects commissioned before 2026, a 1C ratio was assumed (i.e. MWh = MW), reflecting the dominance of one-hour FCR-D optimised systems in that period. For projects from 2026 onwards, a 0.5C ratio was assumed (i.e. MWh = 2 × MW), based on the consistent finding across multiple interviews that a minimum two-hour storage duration is becoming standard for new projects. Furthermore, project purposes and associated power production categories were also standardised across entries to enable consistent quantitative comparison.

The cleaned dataset was analysed across the following dimensions, summarised in Table 3.3.

Table 3.3: Analytical dimensions applied to the BESS database.

Analytical dimension
Growth of installed capacity (MW) per year
Cumulative MW and MWh by year and planning horizon
Share of operational vs. announced vs. unconfirmed projects
Comparison with external datasets to assess validity
Trends in storage duration (MW/MWh ratio) over time
Geographical distribution across Swedish bidding zones over time

3.4.2 Qualitative Analysis

The qualitative data analysis draws on the methodology outlined by Gioia et al. (2013) to ensure rigorous and transparent processing of the empirical data. Gioia et al. (2013) describe a process in which the researcher first codes the data by adhering closely to the informants' own terms and concepts, before grouping and comparing these initial codes into broader researcher-driven themes, which are then further distilled into overarching aggregate dimensions.

Before applying this approach, the transcripts from the interviews were condensed into structured summaries, and cross-checked against the manual notes taken during each interview, to ensure accuracy and completeness. For the two unrecorded interviews, the manual notes were used directly.

The qualitative data analysis followed an iterative coding process in which interview summaries were first condensed into thematic concepts, which were then grouped into recurring themes and further clustered into five overarching dimensions that structure the analysis: 'development of BESS in Sweden', 'market dynamics', 'grid integration', 'local grid support', and 'industrial integration', consistent with the approach outlined by Gioia et al. (2013).

The qualitative and quantitative findings were subsequently integrated thematically in the analysis chapter, which is structured around the five aggregated dimensions. Each theme draws on both the database and interview findings to present a combined picture of the current state and trajectory of the Swedish BESS market.

3.5 Validity and Limitations

To strengthen the validity of the study, several measures were taken into account. Firstly, the actor types represented in the interview phase were diversified to reduce the risk of one-sided perspective. Secondly, the interviewee validation step, in which all used excerpts were returned for review, further improves accuracy. Also, cross-referencing the BESS database against external datasets, mentioned in the section 3.3.1 provided a further check on data completeness and reliability. The BESS database was additionally cross-check against SCB and Svenska Kraftnät prequalified volumes for FCR-D market.

There are nonetheless relevant limitations. The BESS database is comprehensive but not flawless. Projects with or without a public announcement may have been missed, or that the status of the projects could not be confirmed correctly.

The outcome of the qualitative analysis is inherently dependent on the number of interviews feasible to conduct during a time-constrained thesis, as well as the willingness of relevant actors to participate. Additionally, the use of semi-structured interviews may yield responses that fall outside the defined scope of this study. In cases where multiple actors highlight such out-of-scope factors, they are not analyzed in depth but may instead be noted to identify important and emerging themes for future research.

3.6 Ethical Consideration

To ensure transparency, confidentiality and protection of data, a primary ethical consideration in this thesis involves the handling of both quantitative and qualitative data.

During the data collection phase for the BESS database, careful distinction was made between public and non-public data. While information regarding BESS ownership retrieved from public sources, such as official press statements, was openly documented. Any ownership data acquired through non-public or confidential channels was strictly anonymized. This approach ensured that no commercially sensitive information was disclosed without authorization.

For the qualitative phase, strict ethical protocols were followed during the semi-structured interviews. Before each interview session, the respondents were informed about the purpose of the study. Also, permission was requested to record and transcribe the interviews. Furthermore, respondents were asked for their consent before their personal names or associated organisation were used in the report. If such consent was declined, the respondents and organisations were anonymized.

3.7 Artificial Intelligence Usage and Consideration

To ensure full transparency in this thesis, the use of artificial intelligence (AI) tools is documented here. The application of AI is growing in academic research, and was used to streamline specific tasks that will be explained in this section.

When handling the qualitative data, the AI models ChatGPT and Gemini were used to process interview transcripts, which were either generated directly via Teams or transcribed from recorded audio files. The primary purpose in this stage was to convert extensive transcripts into structured summaries. To mitigate the risk of algorithmic bias or misinterpretation, a specific and standardised prompt was utilised (detailed in Appendix C). This prompt explicitly constrained the AI to reproduce the respondents statements in continuous prose and categorise them by theme, strictly prohibiting any addition of independent analysis or conclusion. To ensure the quality, a manual validation was done by cross-checking the AI summary with handwritten notes taken during the corresponding interviews.

Beyond transcript processing, the AI models Claude and Gemini were used for language refinement, such as grammar correction, format suggestions and stylistic improvements, to text first drafted by the authors. Additionally, these were also employed as a technical support tools to generate LaTeX code for table and figure formatting.

4
Results and Analysis

This section presents and analyses the findings from both the data collection and the conducted interviews. The analysis is structured thematically, beginning with the current market landscape and its historical development, before examining market dynamics, grid integration, local grid support, and industrial integration.

4.1 The Development of BESS

This section provides an overview of the current state of the Swedish large-scale BESS market, drawing on both the collected data and insights from the conducted interviews. It begins by presenting the scope and composition of identified BESS projects in Sweden, before laying out the market's historical development and the forces that have shaped its growth trajectory. The section closes with a brief outlook on where the market is heading, laying the groundwork for the deeper thematic analysis that follows in subsequent sections.

The data collection identified 133 separate BESS projects that were grouped in four categories (Figure 4.1). Of these, 89 projects were confirmed as operational, 34 were announced as planned projects with no further confirmation, and the remaining 10 projects were either under construction or previously announced but not confirmed as operational. The total confirmed operational power is 1300 MW, although it could potentially be closer to 1450MW if assuming the not confirmed projects are fully operational (Figure 4.2). Even though the announced projects only constituted a quarter of total number of projects, they represented a larger share of installed power (MW) than the currently operational projects, pointing towards that future projects are larger in size.

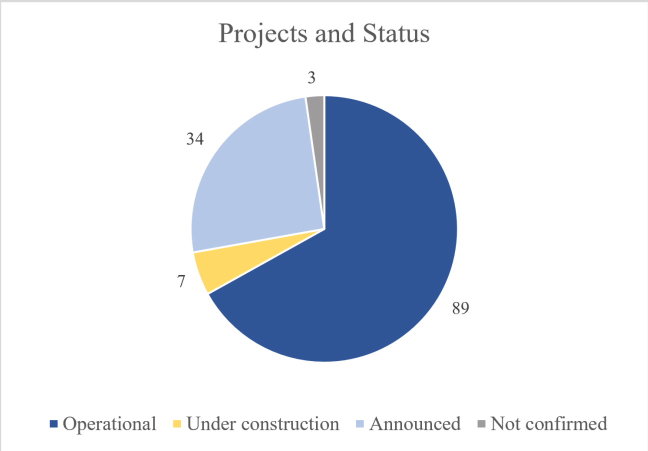


Figure 4.1: Total number of BESS projects in Sweden exceeding 1 MW, distributed by project status.

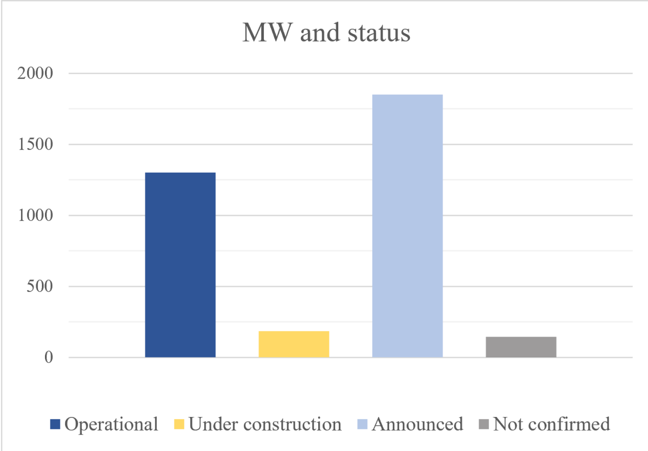


Figure 4.2: Total MW collected per status category for BESS projects in Sweden exceeding 1 MW.

The need of large-scale BESS can be traced back to structural changes in the Swedish power grid system during the late 2010s. The increasing share of variable renewable production and the decommissioning of nuclear reactors such as Ringhals and Oskarshamn reduced the physical rotational inertia in the grid, increasing the need of fast-responding stabilising resources (Interviewee 5, 14). The dry summer of 2018 further exposed the vulnerability of the system and acted as a catalyst for Svenska Kraftnät to accelerate the procurement of stabilising resources. Actors able to participate in these markets were initially highly compensated, and a first wave of BESS emerged largely as hybrid solutions connected to existing hydropower plants, helping older turbines meet tightened FCR requirements by delivering fast power during the initial response period (Interviewee 10, 14).

The very first identified large-scale BESS was built in 2019. From this year until 2023, overall development remained limited, with modest annual additions and relatively small number of projects reaching operational status each year (Figure 4.3). From 2024 onward, however, a sharp acceleration in operational capacity is visible. This largely reflects the commissioning of projects planned during the first major wave of BESS investments. These investment decisions, primarily made between 2022 and 2023, were driven by the extraordinary profitability of the FCR-D market, where payback periods as short as three to six months attracted significant capital (Interviewee 1, 6). The energy crisis of 2022 acted as a major catalyst for this investment wave, as high spot prices increased the compensation required for ancillary service providers. Furthermore, the simultaneous introduction of FCR-D Down (the ancillary service managing grid over-frequencies) generated additional market optimism, ultimately culminating in the high commissioning rates observed from 2024 onwards (Interviewee 14).

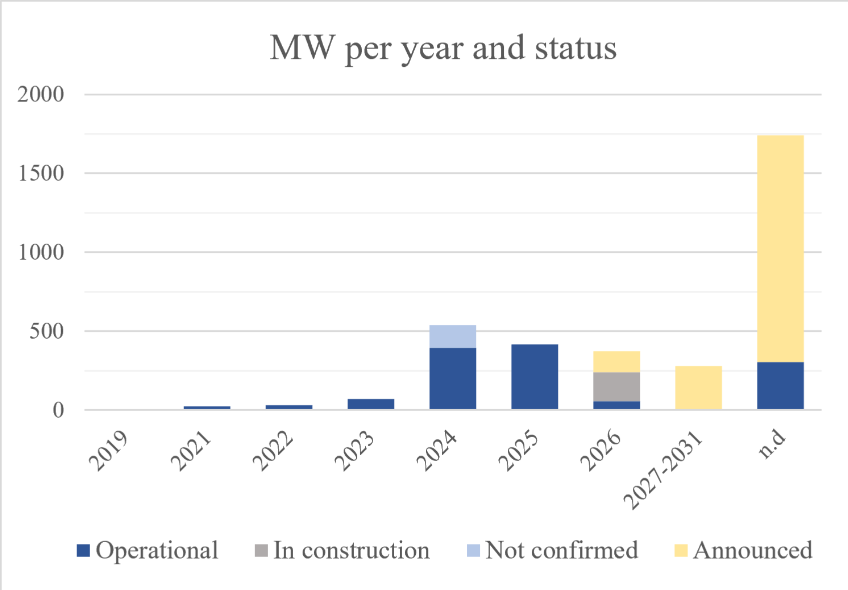


Figure 4.3: Annual installed power capacity (MW) of BESS projects in Sweden exceeding 1 MW, distributed by project status and year, or if no year could be found "n.d" is written instead. No projects were identified for 2020.

However, this period of exceptional profitability was short-lived. As battery capacity on the frequency markets grew rapidly, supply began to outpace Svenska Kraftnät's volume needs, causing FCR-D prices to fall dramatically. Several interviewees described the FCR-D market as having effectively collapsed as a primary revenue source, with the installed capacity of stationary BESS already being sufficient to cover Sweden's entire need for FCR services (Interviewee 4, 12).

As FCR-D revenues declined, the focus shifted toward the newly introduced mFRR market, which offered higher revenues partly due to its relative immaturity and the initially limited number of actors able to meet its requirements (Interviewee 5). Because securing a grid connection is mandatory for developing any new BESS site, the rate of new projects initiations is closely tied to fluctuations in market profitability. Consequently, when mFRR emerged as a lucrative new revenue stream, it triggered a renewed wave of project development, resulting in a rapid influx of new connection applications to DSOs (Interviewee 8). However, several interviewees noted that mFRR is also expected to mature and saturate over time, suggesting the market is undergoing a broader structural transition rather than simply replacing one dominant revenue stream with another (Interviewee 4, 5).

This pattern of growth is further illustrated by the cumulative graph shown in Figure 4.4, which shows that the total power and capacity of BESS increased substantially from 2024 and onwards too. The pipeline of announced projects remains very large compared to what is already operational and the potential power and capacity reaches almost 3500 MW and 6000 MWh, if all projects are realised. This continued growth, in parallel with the FCR-D saturation, points towards that the market is not contracting, but rather recalibrating.

A further trend visible in Figure 4.4 is the shifting ratio between the power (MW) and capacity (MWh). Up until 2026, the development of MW and MWh were relatively similar, since most early projects were scaling their BESS for mainly the FCR-D markets (Interviewee 6, 14). From 2026 and onwards however, a shift can be seen towards longer duration in the batteries, illustrating a change in how new BESS are being designed, which will be further discussed in the following sections.

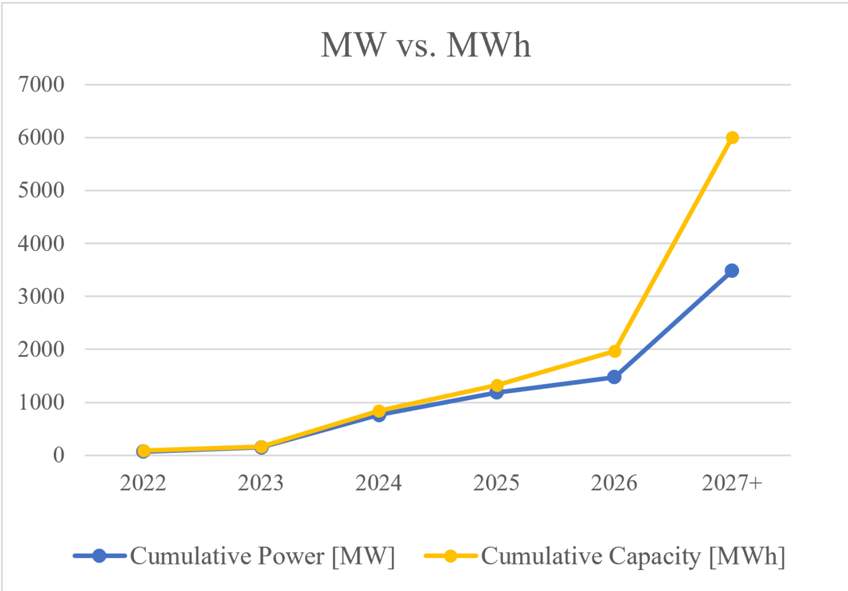


Figure 4.4: Cumulative power (MW) and energy capacity (MWh) of BESS projects from the year 2022, by year and planning horizon. All “operational n.d” (seen in Figure 4.3) projects have been proportionally distributed between 2019-2026

The development described throughout this section is visually summarised in Figure 4.5, which maps the key events of BESS deployment in Sweden onto a stylised S-curve. Starting from the first experimental installations in 2019, through the FCR-D boom and its subsequent saturation, to the current recalibration toward value stacking and longer-duration systems, the figure offers a condensed visual overview of the trajectory described in this section.

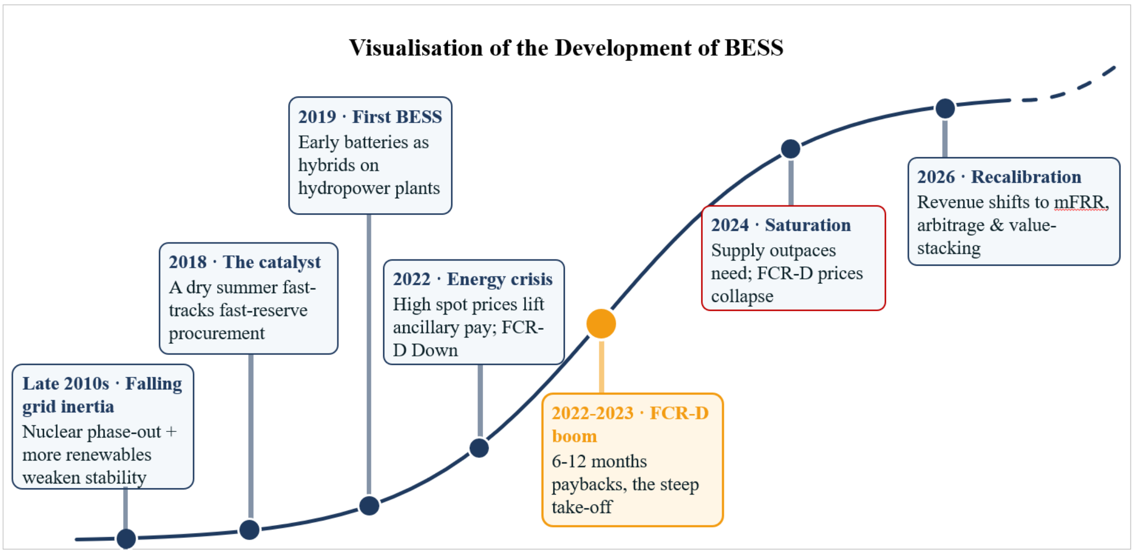


Figure 4.5: Visualisation of the historical development of BESS in Sweden with respect to time and adoption.

4.2 Markets Dynamics

The Swedish BESS market has from the beginning been closely tied to the ancillary service markets operated by Svenska Kraftnät. As described in the previous section, the profitability in the FCR-D market was the starting point for the acceleration of BESS, however, its saturation has fundamentally changed how BESS is applied and operated. What has emerged after the recession of the FCR-D market is not a new single dominant market but rather a more complex landscape where value creation is spread across multiple revenue streams simultaneously.

Following the collapse of the FCR-D market, mFRR has quickly emerged as the dominant revenue source for most BESS operators (Interviewee 3, 4, 12). Several interviewees described this shift as a natural consequence since actors often move toward whichever market offers the best returns. However, participating in these markets is not without its challenges. Delivering ancillary services in general requires extensive technical testing, strict documentation, and complex daily bidding processes, creating relatively high entry barriers, particularly for smaller and newer actors (Interviewee 1). As a result, many operators have become increasingly dependent on third-party aggregators and optimizers to navigate the complexity of market participation. This dependency is expected to increase in the future (Interviewee 1, 3). Accessing the aFRR market reveals an even more fundamental physical barrier than other markets, since participation requires a dedicated ICCP fiber link for communication with Svenska Kraftnät. Since this infrastructure is traditionally only available at larger facilities like hydropower plants and grid operation centers, most standalone BESS operators are effectively locked out of the market entirely, regardless of their underlying technical capabilities (Interviewee 3).

Alongside mFRR, energy arbitrage has also gained significant attention as a complementary revenue stream. According to several BESS developers, arbitrage is becoming increasingly attractive because of increasing electricity price volatility, particularly in bidding zones SE3 and SE4 where the volatility is largest (Interviewee 4, 5, 6). This is further driven by the transition to 15-minute settlement intervals, which has made imbalances in the grid substantially more expensive, contributing to growing activity on intraday and day-ahead markets (Interviewee 5, 17). The shift toward arbitrage, intraday and day-ahead markets have direct technical consequences. To gain profit from these markets, the battery needs to deliver energy over longer periods of time, which has driven the technical development of BESS towards longer storage duration (lower C-value) (Figure 4.6). For the early FCR-D markets, a storage duration of one hour was sufficient, however, as mentioned above, this is now moving towards two and in some cases three- or four-hour systems (Interviewee 2, 3, 4, 10, 12). The earlier batteries are therefore facing new challenges in competing in a market they are no longer optimised for. Expanding already established sites could be a more attractive path forward than investing in entirely new ones, both because existing installations will need to increase their energy capacity to remain competitive, and because adding MWh does not necessarily require additional grid connection capacity, avoiding the cost and lead time of a new connection point (Interviewee 2).

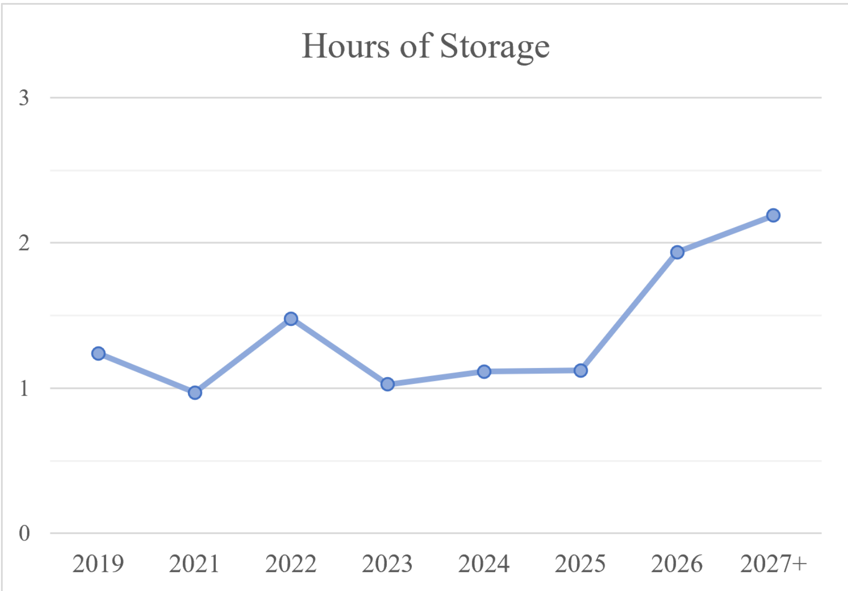
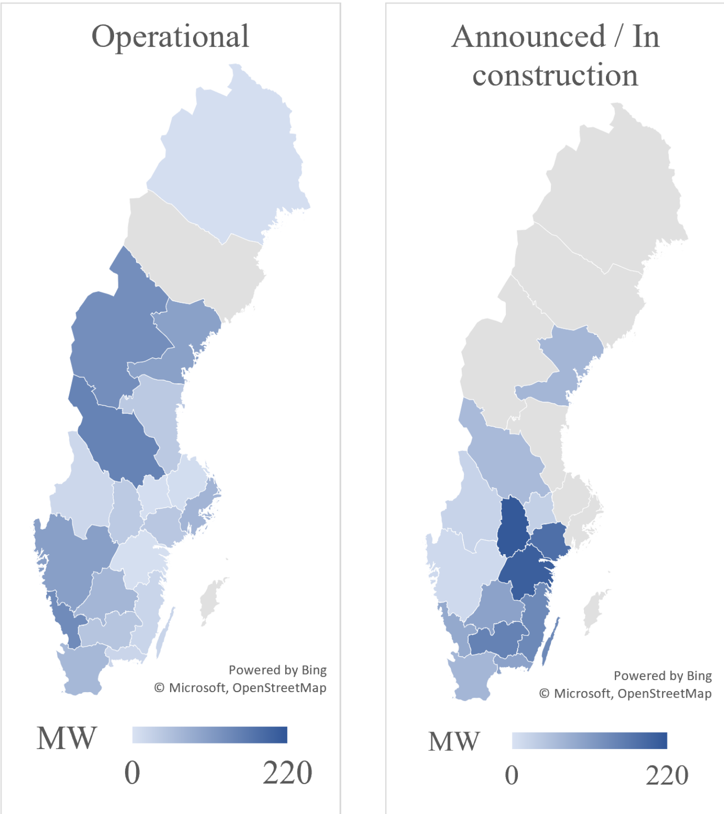


Figure 4.6: Average storage duration (MWh/MW) of BESS projects in Sweden exceeding 1 MW, by year and planning horizon.

There are also geographical implications of this market-shift, where new BESS installations are increasingly concentrated to bidding zones SE3 and SE4. In these regions, a lack of flexible local production capacity drives higher energy price volatility, which in turn creates a larger and more lucrative mFRR market (Interviewee 1, 10, 14). Svenska Kraftnät's implementation of flow-based capacity calculation has further reinforced this dynamic, as SE3 and SE4 must increasingly manage their intraday imbalances using their own local resources, further increasing the attractiveness of BESS deployment in these regions (Interviewee 5, 12). This pattern is also reflected in the collected data and can be seen in Figure 4.7 which illustrates that there is a shift, especially where more announced future projects are concentrated in SE3 and SE4.



Zone	Growth
SE1	0%
SE2	42%
SE3	151%
SE4	207%

Figure 4.7: BESS capacity by county: operational vs. announced/in construction, and growth per bidding zone.

The growing complexity of operating across multiple markets has made value stacking a central concept in how BESS operators approach profitability. With no single market currently offering the lucrative returns once seen in FCR-D, BESS developers and electricity suppliers emphasize that dynamically shifting between revenue streams has transitioned from a strategic advantage to a necessity (Interviewee 1, 3, 13). The development towards value-stacking has also created strong incentives to co-locate BESS where complementary value can be captured alongside market revenues, such as with renewable energy production or industrial facilities, which will be further discussed in the subsection Industrial Integration.

Beyond the ancillary service markets, the expansion of intermittent renewable generation creates a broader systemic need for flexible resources. As traditional baseload generation decreases relative to weather-dependent energy sources, the overall power grid increasingly requires large-scale storage to manage supply fluctuations and maintain system stability.

Alongside these system-level requirements, a compelling local business case has emerged for co-locating BESS directly with renewable production sites. When solar and wind generation exceeds demand, electricity prices frequently drop to zero unless the excess power is captured and stored (Interviewee 6). BESS enables producers to perform energy arbitrage by shifting this overproduction to hours with higher demand and higher prices. This financial incentive has become so strong that several developers now treat co-location, particularly with solar parks, as a standard practice for all new installations (Interviewee 4, 6).

The ancillary markets operated by BESS are in nature unpredictable, an interviewee reported that approximately 70% of all monthly revenues can stem from as little as five days (Interviewee 2). This leads to another major bottleneck, securing bank financing (Interviewee 6, 13). The underlying issue is how banks calculate risk. Banks are accustomed to the wind and solar industries, where long-term contracts (PPAs) are common and guarantee a stable, predictable income over many years. Batteries, however, mainly earn their revenue on daily ancillary service markets where prices fluctuate significantly from day to day. Without an equivalent long-term agreement for batteries, it can be viewed as too risky, making it difficult for developers to secure loans (Interviewee 13). To overcome this barrier, the industry is experimenting with new financial models. One emerging solution is the development of "hybrid PPAs". By bundling wind, solar, and battery storage together into a single long-term contract for large industrial off-takers, developers can create the stable financial predictability that lenders demand (Interviewee 13).

Looking ahead, several interviewees expect mFRR to remain the dominant revenue source for a few more years before it begins to mature, meanwhile, arbitrage and intraday trading are expected to continue growing and take on an increasingly central role (Interviewee 4, 5). The introduction of PICASSO, connecting the Swedish intraday market to a European platform, is expected to bring further changes to market dynamics. It is anticipated that it will significantly alter the demand for aFRR services, though the full consequences remain difficult to predict (Interviewee 17, 18). Ultimately, this growing complexity means that simply owning a battery is no longer enough to guarantee returns. Profitability now almost entirely revolves around the ability to make the right market decisions at exactly the right time. Because of this, developers are becoming fundamentally dependent on advanced optimization and aggregation services to manage their assets (Interviewee 2).

4.3 Grid Integration

While market dynamics dictate how a battery operates, regulations, grid operators, and technical constraints shape how and where these systems can be connected to the power grid. Integrating BESS into the Swedish power grid is complex in multiple ways, from application process to navigating through a regulatory landscape with little standardisation.

The application process for securing a grid connection is slow, costly, and difficult to navigate, with lead times varying considerably but in the worst cases reaching five to seven years (Interviewee 12). Connection costs represent a further barrier, varying depending on the available capacity at nearby substations. If a substation needs to be expanded to accommodate a new connection, developers may face significantly higher costs than initially anticipated (Interviewee 2). A complement to these costs is the lack of information about where available grid connections exist, this forces developers to rely on informal networks and personal knowledge to identify these viable connection points (Interviewee 5, 7). Finding a suitable location is therefore one of the most resource-intensive aspects of project development, requiring a combination of available grid capacity, reasonably priced land, appropriate project sizing, and a clear system value. All of these conditions are difficult to assess without full access to grid information (Interviewee 5).

An interesting contrast to this general lack of transparency can be found in some parts of the Swedish electricity system, where regional grid owners have provided local DSOs with guidelines specifying how much BESS capacity can be accommodated in their networks. For DSOs that have received such guidelines, the process when evaluating and approving new connection requests becomes more comprehensible. The request can then be assessed against the capacity guidelines, which makes the process slightly less time-consuming than to handle them case-by-case (Interviewee 8). However, this capacity information is generally not available to BESS developers. Instead, it is provided to DSOs to support network planning and decision-making. If such information were systematically developed, it could prove useful to BESS developers by reducing the time consuming process to navigate these connection points on a regional level.

A broader structural challenge amplifying many of these issues is the fragmentation of grid ownership across Sweden. With over 170 DSOs and each operating under separate conditions, there is significant variation in how connection requests are handled, how contracts are structured, and how tariffs are designed (Interviewee 16). This makes it difficult for BESS developers to apply consistent approaches across projects in different grid areas and effectively prevents the emergence of a standardised national framework for BESS deployment. The lack of harmonisation further limits the scalability of BESS at a national level, as developers must navigate a different set of rules and expectations with each new project in a new grid area (Interviewee 7, 8). From a regulatory perspective, enforcing standardised contracts or tariff models across such a varied landscape is described as very difficult due to deeply rooted individualistic grid operations. This situation is further illustrated by the fact of how the recent attempt to standardise tariff regulations, which were due to take effect in January 2027 were promptly revoked, requiring EI to restart the regulatory process from scratch (Interviewee 16).

The RFG framework presents a related but distinct challenge in defining BESS, where views contradict. This framework is meant to clarify responsibilities and definitions on technical standards needed to be followed by energy generators, which as reported by DSOs have greatly assisted their processes of classifying and connecting resources to their grid, BESS included (Interviewee 11). From the perspective of developers, the RFG framework fails to explicitly address BESS, instead generalizing it alongside other energy resources. This not only imposes suboptimal requirements on developers but also leaves room for interpretation by DSOs, thereby risking inconsistent implementation strategies across different grid regions (Interviewee 6). This discrepancy between the different actor types is especially interesting since they are operating on different system levels, with DSOs generally having a broader grid perspective. It also stresses how the framework is experienced by different actors and both its positive and negative aspects.

Despite these challenges there are signs of movement towards greater regulatory clarity. EI is finalising a regulatory stance that would permit grid companies to implement special tariffs specifically for batteries, which could significantly affect the conditions under which BESS projects are connected and operated (Interviewee 16). Svenska Kraftnät is also exploring a zoning concept in which different regions would have allocated grid capacity for specific customer types, potentially establishing BESS as its own distinct category within the connection queue system (Interviewee 16). While neither of these developments has yet taken effect, they suggest that the regulatory landscape is gradually beginning to adapt to the specific characteristics of BESS. Nevertheless, the pace of this adaptation remains slow relative to the speed at which the market itself is developing.

4.4 Local Grid Support

While the previous sections have addressed BESS from the perspective of national market participation and grid connection processes, this section examines the potential for BESS to provide value at the local grid level. This separation is important since the overall logic and drivers behind local grid support are significantly different from those behind the markets discussed earlier.

A starting point for understanding the local grid support dynamic is the contrast between the scale of the national ancillary service markets and the potential value of the electricity grid itself. The estimated total value of Svenska Kraftnät's frequency markets is approximately 6 billion SEK per year, while the power grid market and electricity trading market each represent closer to 50 billion SEK annually (Interviewee 1). This comparison suggests that the real long-term societal value of BESS may not be in ancillary services but in optimising local grids and electricity markets, a potential that currently remains largely underdeveloped. The reason for this gap is not a lack of technical capability, but rather a misalignment of where BESS currently can create revenue, and where the broader system-value lies.

This misalignment stems in part from the structure of incentives facing both BESS operators and DSOs. For BESS operators, the rational choice is to operate at whichever market offers the highest return at any given time, which in practice currently means Svenska Kraftnät's national markets rather than local grid support (Interviewee 13). For DSOs, the incentive structure also points in an unhelpful way, where the current regulatory frameworks generally promote grid construction over the purchase of flexibility resources. Most revenue from local flexibility markets are flowing straight through DSOs, making their return on investment very limited (Interviewee 9). The result is a situation where both DSO and BESS developers face structural disincentives to engage with local flexibility markets, even though there seems to be large potential and exist clear drivers from a system perspective.

An additional challenge regarding BESS deployment is that these projects can sometimes advance faster in grid connection queues compared to other types of infrastructure or industrial developments. This occurs because BESS installations typically have significantly shorter construction times and project lead times. Since current grid allocation principles often favor projects that can utilize the requested capacity quickly, BESS developers can secure grid connections earlier than more complex, long-term projects. In practice, this creates a risk that BESS installations consume scarce local grid capacity at the expense of other socially or economically important developments, such as municipal expansion or industrial electrification. This dynamic creates a tension between the commercial development of BESS and broader regional priorities, leading to an increased questioning of the overall societal value of these projects. If a BESS installation operates solely on national frequency markets without contributing flexibility to the local grid, this tension is further exacerbated, risking a negative impact on public acceptance and the social license for future BESS development.

In order to cope with difficulties in managing grid loads, some DSOs are using conditional agreements. These agreements can allow DSOs to stipulate more specific conditions for BESS to be connected, reducing the associated risks of batteries overloading the grid, such as restricting battery activity during high local grid loads (Interviewee 8). However, conditional agreements are not specifically designed for BESS and carry strict requirements, including a proven capacity shortage and methodological approval from EI, and can only be temporary while awaiting physical grid reinforcement (Interviewee 16). Therefore, the view is split on whether these are sufficient tools for BESS, where some DSOs are using them without reporting any issues, whereas others argue that they are not sufficient at all. There is also no harmonisation in how these agreements are structured across different DSOs, making them difficult to both create and navigate for all parties involved. However, there are signs that conditions are beginning to improve. EI is working to finalise a new regulatory stance that would allow DSOs to create more flexible agreement types with BESS operators, potentially enabling more dynamic and prognosis-based management of battery behaviour in the local grid (Interviewee 16). Additionally, DSOs are seen to gradually move from being passive network owners toward becoming more active operators and utilising flexibility services to manage their networks (Interviewee 9). Combined with an increased understanding of BESS behaviour, DSOs are beginning to relax connection restrictions with the favour of more operationally flexible agreements (Interviewee 8).

Looking ahead, local flexibility markets are gradually emerging and attracting increasing interest, which become an increasingly important revenue stream for BESS operators, and potentially provide more stable revenues than the often volatile national ancillary service markets (Interviewee 13).

4.5 Industrial Integration

Beyond the national electricity- and ancillary markets and local grid support discussed in previous sections, BESS is becoming increasingly attractive within industrial settings. From the perspective of BESS operators, this can be seen as a way of further stacking revenues and creating additional streams of income, which is becoming more important in the current market situation.

The general driver for industrial BESS deployment is cost reduction, from the industrial perspective. By deploying batteries to absorb power consumption peaks, energy-intensive industries can operate with smaller and cheaper grid connections, reducing both upfront connection costs and their ongoing subscription fees (Interviewee 2, 17). BESS can also create room for an increase in operations. By enabling more flexible and strategically planned energy use, it can allow for industries to expand, or assist in the electrification of their operations without needing additional grid capacity (Interviewee 2). For heavy industries, the financial incentives extend further still, as BESS can be used to reduce physical imbalance costs and avoid extreme electricity price spikes in an increasingly volatile market (Interviewee 12).

Despite these drivers, integrating BESS within industrial settings creates specific complications. A persistent challenge is the difficulty for grid owners in distinguishing between industrial electricity consumption and battery charging when both occur behind the same meter. Current tariff structures are designed around industrial consumption patterns, meaning co-located BESS can be penalised with the same heavy tariffs despite serving an entirely different purpose (Interviewee 7). The profitability of a project can therefore deteriorate significantly depending on how the local grid owner applies tariffs, indicating a regulatory barrier that directly undermines the economic case for industrial BESS integration (Interviewee 5). Resolving this requires not just a technical solution but clearer regulatory guidance on how co-located systems should be treated.

A further challenge concerns the quantification of actual climate benefits. While BESS can contribute meaningfully to an industry's sustainability goals, these benefits are difficult to measure and harder still to document in a way that satisfies the stringent criteria for state-funded investment grants (Interviewee 2). Unlike solar panels, where the displacement of purchased grid electricity can be calculated relatively directly, the climate contribution of a battery depends heavily on its operational profile, specifically, the carbon intensity of the grid during the exact hours it charges and discharges. This complexity makes it considerably harder for BESS projects to mathematically prove their carbon reduction potential and access public investment support. Clarifying these environmental metrics or establishing dedicated financial incentives for industrial BESS could accelerate deployment in a segment of the market with significant untapped potential.

The number of companies actively seeking to optimise their electricity use is growing, and BESS is increasingly being considered as an integrated part of industrial energy planning rather than an optional add-on (Interviewee 2, 3). Looking ahead, the trajectory for industrial BESS integration appears strongly positive. One interviewee stated that within ten years, battery storage is expected to become standard practice for energy-intensive industries with high power peaks (Interviewee 2).

4.6 Mapping the Data Landscape

Effective technology monitoring of BESS requires reliable, detailed, and up-to-date data on installed capacity, operational use, and market participation. The process of building the quantitative database for this study highlighted how this is challenging. Since there does not exist any centralised registry or reporting channel providing a complete picture, data had to be gathered manually from press releases, developer websites, and public announcements. Understanding why this gap exists requires looking at how data on BESS is currently distributed across the actor landscape, and why bringing it together is structurally difficult.

The actors closest to BESS deployment are distribution system operators. DSOs receive mandatory notifications (*anmälningsplikt*) and installation approvals for all batteries connected to their grids, giving them comprehensive knowledge of installed capacity within their concession areas (Interviewee 11). In principle, this makes DSOs the most complete source of connection data in the country. However, several barriers limit the usefulness of this data for external monitoring. GDPR restrictions prevent DSOs from sharing identifying information about specific installations with external parties, and even aggregated figures can be problematic in grid areas with few installations. However, regulatory authorities do have the legal basis to access this data where the general public does not (Interviewee 11). Beyond this, DSOs know that a battery exists and how large it is, but not how it is operated or which markets it serves (Interviewee 11). This becomes particularly difficult when a battery is co-located behind a shared metering point with an industrial facility or solar park, making it hard to isolate BESS-specific data from the combined profile (Interviewee 8). A further complication is that energy storage was added as a distinct category in grid information systems relatively late, meaning older installations may not be correctly classified (Interviewee 11). There is also no standardised method for how DSOs collect and record battery data nationally, meaning accuracy and completeness varies across grid operators (Interviewee 3, 8).

At the transmission level, Svenska Kraftnät holds prequalification data for all assets participating in the ancillary service markets, providing a view of market participation rather than physical connections. The most meaningful way to use SvK's prequalification statistics for monitoring purposes is to identify the highest prequalified volume across a single market, such as FCR-D, as a conservative floor estimate of connected BESS capacity, rather than summing across markets, since the same battery is typically prequalified for multiple services (Interviewee 1). However, this data is mixed with aggregators using smaller BESS and also lags reality by several months as the prequalification process takes time after a battery comes online. It also only captures whether a battery is eligible to participate, not how it actually operates in practice (Interviewee 1). The actors best positioned to provide the operational layer are BSPs and aggregators, who actively dispatch BESS across markets and hold detailed data on how batteries are actually being used. Since third-party optimisation is the norm for most utility-scale BESS, BSPs collectively hold a picture of operational BESS behaviour that no regulatory dataset currently captures (Interviewee 1, 3).

The official statistical channel for BESS data sits with Energimyndigheten, which since around 2021 has been building a battery-specific data collection as part of the annual energy statistics survey administered by SCB. DSOs are the designated respondents, and the survey captures nominal power and storage capacity. This is a meaningful step forward towards a national monitoring of BESS. However, several limitations remain. The data may be underreported, particularly for smaller systems where reporting practices among installers are inconsistent (Interviewee 19). It is aggregated at national level only with no breakdown by bidding zone, and it is not published until around ten months after the reporting period ends (Interviewee 19). Notably, only one interviewee outside of Energimyndigheten was aware that this data collection existed, despite several others expressing a clear interest in better BESS data (Interviewee 8). This points to a gap between data production and dissemination: a dataset that is poorly communicated to the sector and published with a ten-month lag is primarily useful for looking back at past deployment, rather than a tool for tracking current developments or informing decisions.

Taken together, this landscape reveals a fragmentation in which no single actor holds a complete picture of the Swedish BESS fleet. DSOs see the physical connection layer, SvK sees market eligibility, BSPs see operational dispatch, and Energimyndigheten captures a lagged statistical aggregate. More crucially, these datasets are not connected. The most practical near-term improvement would be to combine DSO connection data with SvK prequalification volumes. Both datasets are held by regulated entities and are accessible to authorities, and together they would cover both the physical connection and the most common market dimensions (Interviewee 1, 11). While BSP data would offer a more complete operational picture, it sits with private actors, and may not be as easily accessible for systematic monitoring.

Looking further ahead, the current reporting flow involves an unnecessary inefficiency: BESS developers already report installations to DSOs via reporting duty, and DSOs must then re-compile this information when reporting to SCB and Energimyndigheten. A more efficient approach would be a national database into which BESS owners report directly, with DSOs confirming rather than compiling. This would standardise data collection across grid operators, reduce the administrative burden on DSOs, and make the data more up to date by moving away from an annual survey cycle toward a more continuously updated national register.

5 Discussion

In this section, the findings of the study will be discussed by first a theoretical reflection, then revisiting the research questions, followed by a discussion of the limitations and potential future studies.

5.1 Theoretical Reflection

The thematic analysis in the preceding chapter was not structured around the theoretical frameworks introduced in Chapter 2. Having established the empirical picture, this section briefly reflects on a few aspects where the frameworks may offer additional perspective, particularly where certain dynamics are less visible in the analysis, or where notable absences are worth acknowledging.

Uneven Function Performance and Representation

As mentioned in the theory, the TIS framework identifies seven systemic functions whose collective performance determines whether an innovation system can sustain its own development. Looking across the analysis, these functions are not equally present, and the difference is itself informative, since it may show where attention and activity is concentrated.

Market formation and entrepreneurial experimentation are clearly the strongest functions in the Swedish BESS system. The rapid growth in installed capacity, the emergence of new application domains, and the active experimentation with value-stacking all point to a system that has been effective at generating commercial opportunities. However, legitimation is more ambiguous. BESS has a strong commercial legitimacy among market actors, but its institutional legitimacy remains more uncertain. The lack of a clear regulatory identity, which is visible in both the RFG classification issue and the inconsistent treatment across DSOs, shows that the technology still occupies an unclear position in the formal institutional landscape. This in itself reflects weak legitimation at the systemic level.

Two functions stand out by their relative absence in the analysis: knowledge development and diffusion, and development of positive externalities. The first is notable because while knowledge is clearly accumulating among commercial actors such as developers, BSPs, and aggregators, there is little evidence of this knowledge reaching the broader actor landscape. It was noted during the interviews that politicians and regulatory authorities lack sufficient technical understanding of how BESS operates, which limits the development of effective regulation. At the same time, there are signs that this gap is gradually closing at the DSO level, where growing hands-on experience with BESS is leading to more flexible and less restrictive connection practices. Knowledge diffusion is therefore not absent, but it is slow and uneven across actor types.

The development of positive externalities was relatively absent from the analysis, though not because BESS lacks the capacity to generate them. BESS could technically provide spillover benefits such as local congestion relief as a byproduct of its normal operation. However, the current regulatory and incentive structure does not enable this potential to materialise, the conditions for these externalities to emerge simply are not in place yet.

Resource mobilisation presents a more nuanced picture. Capital is clearly flowing into the sector, and the speed of market growth suggests that financing has not been a binding constraint at the aggregate level. However, the lack of regulatory clarity and stable long-term revenue mechanisms creates specific barriers for certain types of investors, meaning that resource mobilisation is more complex and uneven than the overall growth figures suggest. Interestingly, while resource mobilisation also encompasses human capital, the availability of a competent workforce was not raised as a barrier by any of the interviewees. This suggests that the market's rapid expansion is currently constrained by institutional and regulatory bottlenecks rather than a lack of technical expertise or labor.

Regime-Level Dynamics

From an MLP perspective, the relationship between BESS and the existing energy system regime appears largely complementary in the current phase. BESS fills a system need created by reduced rotational inertia and increased renewable intermittency, fitting into isolated market structures without necessarily challenging the regime. Where a more disruptive dynamic could emerge is in the local flexibility and grid resource applications. Such use cases could begin to challenge the underlying logic of the regime, where grid stability has traditionally depended on physical infrastructure investment and largely linear flows of energy. The fact that these applications remain underdeveloped, and that the barriers to them are largely institutional rather than technical, raises the question of whether this reflects a structural resistance at the regime level to a more transformative role for BESS, or simply that existing institutions and incentive structures were designed around a different technological reality and have not yet adapted.

Differentiated Phase Positioning

The characterisation of BESS being in a late formative or early growth phase is consistent with what the analysis shows. The conditions Bergek et al. (2008) associate with the formative phase are recognisable: institutional underdevelopment, weak standardisation, and the absence of self-reinforcing mechanisms at the systemic level. At the same time, the scale and pace of market growth, and the emergence of multiple simultaneous application niches, are more consistent with the early stages of a growth phase.

What the analysis makes clear, however, is that this phase positioning does not apply equally across all application segments. The FCR-D niche has effectively completed its S-curve and entered saturation. The mFRR niche is in active growth. Co-location with renewables is accelerating. Local grid support and industrial integration remain at an earlier and less developed stage. Some segments have already moved through their formative phase while others are still in it. This differentiation cannot be fully captured by a single phase label, and is therefore better explained by the overlapping S-curve framework.

5.2 Revisiting the Research Questions

RQ1. How large is the currently operational and future planned BESS capacity in Sweden?
The data-collection identified 133 projects with a total power and energy capacity of roughly 3500 MW/6000 MWh. The current operational projects constitute 1300 MW/1450 MWh of the database. This estimate is closely aligned with data from Svenska Kraftnät for the prequalified resources for FCR-D market, an indication of data comprehensiveness. By the end of 2026, the data anticipate a total power and capacity of 1620 MW/2050 MWh, including the projects that are operational and under construction.

RQ2. What are the drivers and barriers behind the development of BESS?
The initial catalyst for BESS development was the exceptional profitability of the FCR-D market. Today, it is not a single driver pushing the market, instead more attention is given toward value-stacking methods and optimising several revenue flows simultaneously. The most attractive driver is seemingly the mFRR market and increasing attention is also being given to arbitrage trading. The incentives of co-locating BESS with both industries for peak shaving and renewable energy for production shifting are also becoming more evident. Another driver for BESS is the opportunities in local flexibility markets, however, this application is still in an early phase.

The barriers to further development are mainly institutional, and together they hinder the technological systems' transition into a full growth-phase. Uncertainty regarding both the development of ancillary services markets and future regulatory frameworks create reservations towards investing. Simultaneously, the lack of standardisation in combination with a fragmented DSO landscape creates a challenging environment for BESS developers to navigate, making the development process more labor-intensive. The additional reported ambiguity in the definitions of BESS reduces the legitimacy, as it means the technology lacks a specific institutional identity, resulting in inconsistent rules and requirements. Other barriers are more structural and refer to the grid integration of BESS, such as long queues, expensive connections and low transparency regarding the grid architecture, making the process of operationalising BESS more labor-intensive.

RQ3. Which trends can be seen in the market and what are the future characteristics of BESS?

As mentioned in RQ2, if compared to the early single-purpose use-case of BESS, a significant shift can be seen towards diversification of revenue streams and increased focus on optimisation across these markets. This diversification also reaches outside of conventional ancillary markets into other application niches such as co-location with industries and renewable energy production but also integration in local flexibility markets, to further solidify the business case. This shift is reflected in a more deliberate approach to siting, where location is more central and strategically chosen to capture a broader value-spectrum.

A geographical trend is the shift towards more development of BESS in bidding zones SE3 and SE4, due to higher mFRR profitability. Led by the change towards energy-intensive markets, the capacity and storage-time of BESS is increasing (decreasing C-rate), where the future standard is expected to be 2-4h systems.

Looking ahead, mFRR is expected to remain the dominant driver for a couple of years. Co-location with BESS is likely to become more common in industries and a standard addition to renewable energy production. Pilot applications for island-mode operations and black-starts are emerging and, although in a nursing phase now, may become more common in the future.

RQ4. How can data availability improve to facilitate technology monitoring of BESS?

Effective monitoring of the BESS market is currently hindered by a highly fragmented data landscape. No single actor holds a complete overview of the Swedish BESS, the available data is further scattered across different systemic levels. DSOs possess data on physical grid connections but lack operational insights. At the transmission level, Svenska Kraftnät holds market prequalification data, which reflects market eligibility rather than actual physical dispatch. Furthermore, the official statistical data collected by the Swedish Energy Agency suffers from time lags and lacks regional breakdown.

To improve data availability in the near term, the most practical approach is to combine datasets already held by regulated authorities. Integrating DSOs physical connection data with Svenska Kraftnät's prequalification volumes would effectively bridge the gap between the physical connection layer and market participation. In a longer perspective, the structural inefficiencies in the current reporting flow must be addressed. Establishing a continuously updated national database where BESS operators report directly, with DSOs only confirming the connection, would significantly streamline the process. This would standardize data collection across grid operators, reduce the administrative burden on DSOs, and provide a real-time monitoring tool rather than relying on delayed annual surveys.

5.3 Limitations and Future Research

5.3.1 Limitations

When interpreting the results of this study, it is important to acknowledge that a degree of bias cannot be excluded. Since most of the interviewees are directly connected to BESS with commercial interests, their assessment of drivers, barriers, and market dynamics may be influenced by their own position in the market. For instance, a grid owner (DSO) may frame barriers very differently compared to a BESS project developer. Although this diversity in perspectives provides a comprehensive overview of the market, it is an important factor to consider when evaluating the overall findings.

A limitation of the quantitative database is the large proportion of projects currently classified as 'announced'. While the exact date of announcement were not analysed, it is highly likely that many were published during periods of high market profitability and lower price volatility. As market conditions have shifted since there is a risk that some of these announced projects may either be cancelled or redesigned, such as by extending the storage capacity (lower C-rate), to remain economically viable. A consequence to this is that the projected future capacity may be overestimated.

5.3.2 Future Research

Due to the novelty of BESS, there are multiple avenues for future research. Drawing from the identified barriers, areas of interest are primarily regulatory and institutional. However, technical capabilities are also highly relevant for further studies, such as the potential of contributing as sustained grid resources and will be further discussed below.

One area of interest would be to investigate the current legal and technical definitions of BESS. The current regulatory interpretation is often experienced as ambiguous by some BESS developers, yet viewed as functional by DSOs. It is therefore highly relevant to identify these regulatory bottlenecks and future research could explore how these definitions may be reformed to better suit all market actors.

A relevant but distinct research area is whether BESS could be more formally integrated as a structural grid resource operated or contracted by DSOs. The primary objective here would be to understand how BESS can assist grid infrastructure as either a complement or an alternative to physical grid expansion. Such a study should include economic, technological, and environmental aspects. Furthermore, since the BESS business model relies heavily on optimization and value-stacking, restricting batteries solely to either grid infrastructure or commercial arbitrage is likely sub-optimal. Therefore, future studies should explore new regulatory frameworks that enable a hybrid model, allowing batteries to provide dedicated grid benefits while simultaneously maintaining the flexibility to operate in other commercial markets.

Another research area is to explore the mechanisms within local flexibility markets. Since there is currently no standardised framework for DSOs on how to operate these markets, a broader, national development would require more distinct guidelines on how these markets are created and what they require. This research would also need to explore more specifically what impact regulatory frameworks have and where they block or induce development. This is especially interesting since there exists a split in where BESS is incentivised to operate, and where BESS may provide the highest system-value.

Finally, the long-term business case for BESS in Sweden will inevitably be shaped by future shifts in the national energy mix. As the political and macroeconomic landscape of the energy sector evolves, future studies could model the impact of introducing new large-scale power generation into the Swedish grid. Research evaluating how an expansion of new baseload power or additional intermittent generation would affect price volatility, energy arbitrage opportunities, and the demand for ancillary services is crucial. Understanding these systemic market shifts is essential for accurately forecasting the long-term risk profile and commercial viability of future BESS investments.

6 Conclusion

The Swedish BESS market is undergoing a transition. The original conditions of high profitability and low competition in the FCR-D markets have faded, and the industry is currently defining its future trajectory. What this thesis concludes is that the answer lies not in a new dominant application, but rather a fundamentally more complex logic where the profitability depends on the optimisation across several markets and revenue streams, more careful site selection, and new niche-applications.

The diversification of BESS into industrial and renewable co-location and local flexibility reflects how the technology is generally broadening its role in the energy system and is also consistent with a typical niche-cumulation process. Yet, what is holding the progression back is not the technical readiness but the institutional barriers surrounding it. The regulatory environment has not kept the pace with the market's development, and the lack of clear definitions, standardised frameworks, grid-access transparency, and missing market structures. These are not problems that time or investment alone will solve.

Ultimately, the future of BESS is not determined by its technical capabilities or commercial viability. It depends on how or whether the institutional landscape can both match the rate of market development, and to successfully realign its incentives to capture the full systemic value. Closing this gap, both in pace and direction, is the most substantial challenge for the market's continued development.

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A

Appendix A

In this Appendix the interview questions is attached.

The interviews started by introducing us and the aim of the thesis. Also, asking for permission to record and transcript the interview.

During the interviews the questions was used as support and was not asked in this exact sequence. It was used to ensure that all the topics were covered before finishing the interview.

General

- How is your company involved with BESS?
- Do you manage or own BESS yourselves? If so, what are its objectives?
- Do you plan to build or connect more BESS in the future?
- Do you have data on what is connected to your grid?

Driving Forces

- What driving forces do you consider most crucial to the development of BESS?

Barriers

- Do you see any significant challenges regarding BESS? Both from your perspective and on a larger scale.
- Do you see any potential future risks?

Trends

- What trends do you see in the BESS market? (e.g., size, business model, types of players, cost trends, geographic location)
- What role do you think BESS will play in the electricity system in the future?
- How much BESS do you think will exist in Sweden in 5–10 years?
- What will drive development the most?

Grid operator perspective (if possible):

- What challenges do you face as a grid operator?
- Are there any bottlenecks between you as a grid operator and BESS project developers?
- Grid expansion: BESS or not? What are your thoughts?

B

Appendix B

Table B.1: Summary of conducted interviews including drivers, barriers, and trends.

#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
1	Checkwatt. Erik Wallnér. Aggregator	• The high profitability of ancillary service markets has made it economically irrational not to connect batteries larger than 1 MW to these markets. • The general decline in LFP battery costs has established the technology as a standard solution for BESS, significantly lowering the cost of investment and improving the overall business case for new projects.	• The electricity grid represents the single largest barrier to BESS deployment, characterized by long connection queues, complex application processes, and high connection costs. • Current power tariff models act as a major brake on the industry, as high fees triggered during battery recharging eat into ancillary service revenues. This creates a contradictory dynamic where operators bid high to avoid activation, leaving batteries standing ready but rarely being used. • Delivering ancillary services, requires extensive technical testing, strict documentation, and complex daily bidding processes, creating high entry barriers for new and smaller actors and driving reliance on third-party aggregators. • Current regulatory frameworks incentivize grid owners to invest in traditional grid infrastructure rather than procuring flexibility services from batteries, even in cases where flexibility would be more cost-effective. • The rapid expansion of battery capacity on frequency service markets has led to oversupply and significantly reduced market profitability. • China controls virtually the entire value chain for battery cell manufacturing, leaving Sweden heavily dependent on imported components with no meaningful domestic production capacity, representing both a supply risk and a strategic vulnerability.	• Falling FCR-D prices, driven by market oversupply, have caused the industry to shift its focus toward the mFRR market. • New BESS installations are increasingly concentrated in price areas SE3 and SE4, where the mFRR up-regulation market is larger and more lucrative due to less flexible local production capacity. • Because connecting massive battery parks is becoming too difficult and expensive, the trend points toward building more widespread, medium-sized systems (e.g., 200 kW) in existing properties rather than massive standalone parks. (personal reflection) • Because bidding, prequalification, and system integration are so complex, project developers and owners will continue to heavily rely on third-party aggregators and optimizers to steer their batteries across different markets.	• The highly profitable FCR-D market was the primary driver behind the initial expansion of battery investments in Sweden, with the strong revenue potential attracting large amounts of capital into the market. • There is a sharp contrast between the size of ancillary service markets (estimated at around 6 billion SEK per year) and the grid and electricity trading markets (each around 50 billion SEK per year), arguing that the real societal value of batteries lies not in ancillary services but in optimizing grids and electricity markets — a potential that remains largely unrealized due to misaligned regulatory incentives. • Significant untapped potential exists for using batteries to optimize local grids and accelerate connection times for industries, though realizing this potential requires grid owners to actively adopt and utilize flexibility-based solutions.
2	Byhmgard. Fredrik Rosengren. BESS Project Developer	• The ageing Swedish power grid, combined with slow expansion, creates a growing need for BESS as a complement to grid infrastructure. • The expansion of solar and wind power creates a need for storage solutions to manage overproduction during periods when the grid cannot absorb the full output. • The ongoing electrification of industries is driving increased electricity demand, creating a growing need for storage solutions to manage capacity constraints. • For energy-intensive industries, BESS offers a means of reducing costs associated with high power peaks and grid subscriptions. • By enabling more flexible and planned energy consumption, BESS can reduce or defer the need for larger grid connections, lowering the associated costs for industrial operators.	• Application processes for grid connection can take three to four years, which is particularly problematic for companies that both sell hardware and hold a long-term ownership interest in BESS projects. • Grid connection costs represent a significant upfront barrier for BESS projects. • Grid capacity availability varies significantly across Sweden, and in many cases actors must wait several years before a connection can be established. • Obtaining approval for larger power connections is particularly challenging, creating a bottleneck for industrial actors seeking to expand their operations. • There are significant variations in how different grid owners prioritise and process BESS-related applications, with some being considerably slower and less resourced than others. • The climate benefits of BESS are difficult to quantify, as they depend on how the system is operated, making it harder to access subsidies compared to technologies such as solar panels where savings can be more directly calculated.	• Early BESS projects were largely designed around FCR-D revenues, but the market has shifted toward value-stacking strategies that combine frequency markets with industrial integration and PPA agreements. • The industry is shifting from one-hour systems toward two and four-hour systems, partly driven by the ability to increase energy capacity without incurring additional connection fees. • Increasing trend of companies/industries that need to optimize their energy-use. • Much of the future growth in BESS is expected to occur at already existing sites, where grid connections are already in place and the associated costs have already been covered. • As batteries move toward longer storage durations, arbitrage is expected to become an increasingly important revenue stream, particularly given the price differentials between peak and off-peak hours. • Optimization of battery operation is becoming increasingly central to profitability, as the ability to make the right market decisions at the right time is described as the single most important factor for revenue. • Within ten years, BESS is expected to be standard practice for energy-intensive industries with high power peaks, driven by grid constraints and the increasing cost of power subscriptions.	• The Swedish BESS market, currently estimated at around 1,600-1,700 MW, is expected to continue growing at approximately 15-20% per year for the next ten years, after which the market is expected to stabilize as grid capacity needs are increasingly met.

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Table B.1 continued from previous page

#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
3	Ellevio Energy Solution. Dennis Bohm. BESS Project Developer	• The high profitability of the FCR-D market in its early years, with payback periods of around two years, was a key driver of investment in BESS — alongside the broader opportunity to participate in ancillary services markets and benefit from electricity price arbitrage. • The desire to diversify risk within an energy portfolio makes BESS an attractive asset, as it can be deployed across multiple markets and revenue streams simultaneously.	• Understanding and complying with new regulatory frameworks, such as the Requirement for Generators (RFG) and EU functional requirements for inverters and batteries, requires significant time and effort from operators. • Participation in energy-intensive markets increases wear and tear on batteries, while also driving up electricity and tax costs, reducing overall profitability. Energy arbitrage is the most demanding in this regard, followed by FCR-N. While mFRR also involves energy delivery, its capacity reservations are less demanding and actual activations occur only sporadically. • Most BESS operators are effectively excluded from the aFRR market, as participation requires a dedicated ICCP fiber link for communication with Svenska Kraftnät, infrastructure that is typically only available at hydropower plants and grid company operation centers.	• mFRR has become the dominant market for BESS operators, overtaking FCR-D as the primary source of revenue. • Energy arbitrage is becoming more common, driven by declining revenues in frequency markets. • Local flexibility markets for peak shaving are emerging as an additional revenue stream for BESS operators. • Batteries are moving toward lower C-values, meaning higher energy capacity relative to power, enabling longer storage times. • The use of aggregators to continuously optimize battery participation across markets is becoming increasingly common. • Power as a Service is emerging as a business model for BESS, though few actors are currently involved.	
4	Anonymised. BESS Project Developer	• A large driver is the need to complement variable renewable production with BESS (all of their planned solar installations will have collocated BESS). • The main drivers/purpose of BESS is production shifting, arbitrage when the sun isn't shining, the frequency market, and intraday trading. • The prices for batteries are decreasing, which makes the overall business case even better.	• The connection time to the grid in Sweden is extremely long. Additionally, it is difficult to find available connection points on the Swedish grid. • The connection time to the regional and transmission grid in Sweden is long. • The connection time is one of the major risks for projects. Even smaller projects (<30 MW) can have a timeline of 7 to 10+ years to connect. • There is significant uncertainty regarding future tariffs and Energimarknadsinspektionens (EI) revenue frameworks. It is difficult to make financing decisions without knowing what the tariffs will look like, as a bad tariff can ruin a project. • The changes in the "intäktsram" for regulation period 5 (RP5) that Energimarknadsinspektionen is intending to implement is significant. The grid owners will need to adjust their income streams to these new rules, but how they are intending to do this is unclear at the moment, which introduces more uncertainty to the project investment. • Connecting a large BESS takes up grid capacity that could otherwise be used for other connections, which is sometimes viewed as not socio-economically justifiable. • Connecting a large BESS (BESS in general) takes up grid capacity, especially if the project has a "prima anslutning". Having a BESS that has "prima anslutning" will entail a poor grid utilization, which is not socio economically optimal. Hence, new grid rules need to be developed, so both the BESS has access to sufficient revenue streams to be realized, while high degree of grid utilization is possible simultaneously. • Data on available grid connections are not public. Makes finding suitable locations difficult. • Little public knowledge on free capacity (grid and transformer) available.	• The FCR-D market has crashed completely. • Recently, FCR-D and FCR-N market prices have decreased and may not be as important for BESS business case in future as those have been up until now. • Currently, the mFRR market brings in the most revenue and will likely continue to do so for a couple of years. • Outlook for mFRR looks to be promising in the coming years. • Over time, the market focus will shift heavily toward energy arbitrage, day-ahead trading, intraday trading, and hedging. But it is difficult to see into the future. • As frequency markets gets saturated, use-case for BESS will likely pivot toward energy markets and hedging. • There is a trend toward longer storage times, as more duration is seen as better. Longer storage duration also results in less wear and tear on the batteries. • As the price for BESS is reduced over time, and use-case for BESS may pivot to energy markets, lower C-rate (more energy per unit power) could prove more feasible. • Other types of energy storage, such as iron batteries and redox flow batteries, are expected to become more common. This is because there are significantly more efficient ways to store energy, allowing for more energy storage per unit of power. • Novel, promising technologies, such as iron batteries and redox flow batteries is likely to offer lower cost per MWh of storage compared to existing technologies once TRL (technical readiness level) is increased and they reach economy of scale.	

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#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
5	Ingrid. Vincent Gliniewicz. BESS Project Developer, Optimiser	• From a system-perspective, the drivers are to create flexibility in the grid. • As a developer the drivers are also financial, and investments are placed where most revenue is available.	• It is difficult to know where a battery may have the greatest benefit to the system since information about this is not publicly available. There is generally a lack of transparency. • For projects to come to fruition, a location with clear system value, a good grid connection and a reasonable size to match the revenue, and cheap land are required for the business calculation to be successful - making projects complex. • Huge amount of work behind finding a suitable location. • Unclear who "owns the system", difficult to create value since the flexibility market is blunt. • If an industrial customer (co-location) is hit with a high tariff, the profitability may decrease drastically.	• Believes strongly in arbitrage for the future, which will make the price more steady and better revenue from investing in solar and wind since production could be smoothed out. • The FCR market has matured and become saturated. Investments and focus are now shifting to mFRR, which is also expected to level off eventually (partly due to current market immaturity and high initial requirements for participants). • The transition to 15-minute settlement periods has made imbalances much more expensive, driving a significant increase in trading close to the hour of operation. • Europe's transition to flow-based capacity calculation model is driving up the prices for balancing the power system.	• På grund av avvecklingen av kärnkraftsreaktorer som Ringhals och Oskarshamn minskade den roterande svängmassan i nätet, vilket skapade ett akut behov av nya stabiliserande resurser. • 95% of all BESS actors do plug and play.
6	Paradisenergi. Johan Paradis. BESS Project Developer	• BESS functions as a buffer for intermittent renewable production, this means that if you don't store the energy, zero prices will occur. • A driver is the revenue on SVK frequency markets, which is typically achieved through revenue stacking. • The returns were so high that the payback period for newly built BESS could be just 3-6 months, which attracted large amounts of investment.	• There is a lack of appropriate regulations for large battery plants. • BESS is not mentioned in the RFG which means that actors are forced to sign the electricity grid owners regulation in order to connect the BESS to the grid, no matter how unclear those regulations are. • The current lack of clear legislation makes it challenging to attract infrastructure funds, which typically require regulatory certainty. • Grid connection is a major expense that can prevent many BESS projects from being built. • It is challenging to correctly size batteries connected to solar parks, as the Final Investment Decisions (FIDs) were made 1-2 years ago under very different market conditions.	• If the electricity prices continue to fluctuate greatly it will be more energy arbitrage in the future. • A strong trend and economic necessity at the moment is to combine batteries with renewable electricity production, primarily solar parks. • The price on batteries has dropped significantly, which makes it possible for investors to get two hours of endurance (storage time) for the same price.	• One political initiative is Kraftlyftet, where the state has invested billions and is offering 30% investment support to build BESS in combination with existing energy production.
7	Powerworks. Viktor Charpentier. BESS Project Developer	• The major driver for BESS is the revenue from SVKs frequency markets. • High market price volatility, significantly driven by interconnectors to the European continent, creates a strong business case for battery storage. • Through better optimization and data analytics, batteries have the potential to reduce the need for large-scale grid expansion, potentially saving society a significant portion of the estimated thousand billion SEK that the grid would otherwise require.	• Lack of regulatory harmonization hinder BESS scalability, such as local grid tariffs and the absence of standardized framework across the DSOs. • Current tariff structures heavily penalize co-located BESS since electricity grid owners cannot distinguish whether it is industry or batteries that consumes electricity. • The lack of long-term mechanisms (e.g., 15-year contracts with SVK) makes it difficult to secure stable revenues and lower the cost of capital for large-scale investments. • Swedish grid capacity data is highly restricted and treated as confidential, forcing developers to rely on "insider relationships" to locate available grid connections. • The market increasingly requires BESS operators to assume the role of Balance Responsible Party (BRP), which acts as a limiting factor and barrier to entry. • A lack of technical understanding among politicians and regulatory authorities limits the development of effective policy and regulation for BESS. Policymakers need deeper hands-on knowledge of the technology to be able to design legislation that genuinely embraces its potential.	• BESS operations are transitioning from relying solely on ancillary services towards energy arbitrage and intraday trading to manage risk profiles. • There is a growing technical trend to equip BESS with "Black start" and "island mode" capabilities to support local grid resilience (e.g., "resilience hubs") during crises, although market mechanisms to monetize this are currently lacking.	

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#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
8	Falu Energi & Vatten. Oscar Willén & Gustav Öhberg. DSO	• The primary driver for BESS is the highly lucrative revenue streams available in SVK's ancillary service markets. • DSOs offering "conditional agreements" (villkorade avtal) act as a strong enabler. These allow developers to connect batteries at significantly reduced connection and monthly capacity fees, provided the BESS is only used for specific purposes like support services or arbitrage. • They have received guidelines from the regional grid owner Ellevio that they have space for 60MW of BESS → Makes it much easier to grant projects as long as they keep it within the limit.	• Grid sizing becomes more complex when batteries, solar panels, and other variable generation must be factored in simultaneously. • Local DSOs cannot financially compete with the high compensation offered by SVK's markets, making it difficult to promote BESS for local grid benefits. • There is a lack of standardization regarding contracts and power charges, which makes management more complex. • Practical limitations beyond grid capacity, such as municipal zoning laws (detaljplaner) and unbuildable land (e.g., near water) close to substations, frequently stall projects. • Long delivery times for equipment such as transformers and other central grid components delay projects. • Electricity grid companies may feel overwhelmed by all the requests coming in for BESS, and therefore may be reluctant to collect data. • A technical challenge lies in separating specific BESS operational data when systems are co-located with industries or solar parks behind a single meter. • The traditional and non-digitalized nature of the electricity grid sector makes many DSOs hesitant to adopt innovative tools like conditional agreements, which require method approvals from the Energy Markets Inspectorate (Ei).	• BESS connection requests are highly reactive to market profitability. Application volumes surged dramatically in 2023, dipped when prices fell, and spiked again with the introduction of mFRR. • The battery storage time is starting to increase. • As local grid operators gain better technical understanding of BESS behaviors, they are becoming less restrictive. For example, moving from strict capacity limitations to allowing full operational freedom, provided the customer bears the financial risk. • For FEV, conditional agreements are sufficient at the moment, all local flexibility markets have been closed. This may become relevant in the future. • The initial boom for large-scale BESS in local distribution grids may be leveling off due to capacity exhaustion. Future utility-scale projects are expected to connect directly to the regional grid. • Most actors seeking to connect BESS are looking for relatively large installations, though smaller projects also exist. Actors have also become more sophisticated in site selection, increasingly seeking locations near distribution stations to minimize connection costs.	• They are optimistic about continued development in home batteries, solar-integrated storage, and, in the long term, electric vehicle batteries and V2G solutions. • The frequency markets are changing rapidly.

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#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
9	Göteborg Energi Elnät. Simon Siöstedt. DSO	• Market-based flexibility enables better utilisation of existing grid infrastructure, allowing more customers to share the same grid capacity more efficiently and reducing the need for costly grid expansion. • Local flexibility can help the DSO optimise its regional grid subscriptions and reduce costs related to exceeding contracted or subscribed grid capacity, for example by using flexible resources to reduce load or inject power during constrained periods. • The power grid is developing too slowly relative to growing demand, and if flexibility resources are not developed now, grid operators risk being unprepared when capacity constraints become critical.	• The absence of well-developed contractual frameworks between DSOs and battery operators limits the ability to use batteries for local grid purposes and creates uncertainty for both parties. • Finding suitable locations for BESS is a significant challenge. It is especially difficult to get permits since the land needs to be weighed against alternative uses such as agriculture. • Current regulatory frameworks incentivize DSOs to invest in grid infrastructure rather than flexibility, as grid investments generate a regulated return on capital while expenditure on flexibility services such as local markets produces very limited financial return for DSOs. • Without appropriate contractual frameworks, battery operators optimizing for national markets could cause local grid congestion and displace other grid users, as their behavior is difficult for DSOs to predict or control. • The absence of a clear regulatory stance from EI on key issues such as flexible connection agreements has created caution among both DSOs and battery operators, slowing the development of new market structures. Also generally for investments in BESS.	• Grid companies across Sweden are moving toward a more active operational role, transitioning from being purely network owners toward becoming distribution system operators that actively manage their networks using tools such as market-based flexibility. • Contractual frameworks between DSOs and battery operators are evolving, with a shift toward prognosis-based agreements that allow for more dynamic and flexible management of battery behavior in the local grid. • BESS installations are increasingly being built with longer storage durations, moving from one-hour systems toward two-hour and in some cases three to four-hour systems, driven by falling battery costs and the growing importance of energy-intensive markets. • Battery costs have fallen significantly, making it more economical to build systems with higher energy capacity relative to installed power. • Profitability in fast frequency markets such as FCR-D has declined significantly, reducing the attractiveness of short-duration, high-power battery configurations. • Market focus is shifting toward more energy-intensive applications such as mFRR, spot trading, and intraday markets, driving demand for batteries with greater energy capacity. • The number of batteries in Sweden is expected to continue growing, with Sweden likely following a similar development trajectory to countries such as the Netherlands, the United Kingdom, and the United States where battery deployment has already progressed further.	• Sweden's dependence on Chinese battery technology represents a security risk, as external actors could potentially influence the software or control systems of batteries connected to critical grid infrastructure. (Personal opinion) • Overreliance on Chinese manufacturing creates a supply risk, as China controls both battery cell production and large parts of the raw material supply chain, giving it significant influence over market conditions. (Personal opinion)
10	Jämtkraft AB. Johanna Renman. BSP/BRP	• A driver for BESS is to participate on SvK frequency markets and maximize the revenue. • One driver for Jämtkraft is to co-locateBESS with their existing hydropower plant to participate on the frequency market after SvK tighten the regulation for FCR market. • A driver for BESS is the energy arbitrage market, which is profitable in SE4 where electricity prices are volatile and high.	• The rapid influx of BESS into the frequency markets has severely depressed FCR prices, squeezing profitability for both BESS and traditional hydropower from this market. • Technological development outpaces supply chains; spare parts for components built as recently as 2021 are already unavailable, making operations and maintenance costly and slow. • Historically low and stable electricity prices in northern Sweden make energy arbitrage not as profitable compared to other bidding zones.	• The market is shifting towards longer-duration BESS (e.g., 2-hour storage) to better suit energy-intensive markets. • New BESS investments are currently concentrated in SE3 and SE4 due to higher price volatility, rather than in the north. • The battery and ancillary services market is highly dynamic and moving fast, requiring constant adaptation from operators to maintain profitability. • While current revenues are largely driven by ancillary services, BESS is viewed as a highly valuable asset for future local flexibility markets and grid stability services.	

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Table B.1 continued from previous page

#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
11	Varberg Energi Elnät. Hans Ljungström. DSO	• BESS can act as a buffer if the DSO faces capacity limitations or disruptions from the overlying regional grid. • A battery can also prove useful by contributing with stability upwards to the regional grid, and combine this with commercial services such as the frequency market or other aggregated services. • The updated Requirements for Generators (RfG) network code has classified energy storage more clearly, simplifying the connection process by establishing technical standards. • Regulatory frameworks allow DSOs to procure local flexibility (e.g., peak shaving from BESS) as an alternative to costly infrastructure upgrades, provided it is the most economic solution.	• Some older batteries have not necessarily been classified as energy storages in the system from the start (making the mapping a bit unsure). • While DSOs know the exact installed capacities in their grids, GDPR and privacy laws strictly prohibit them from sharing identifying BESS data with external mapping projects, making national consolidation challenging. • Peak shaving is needed very rarely, only during very short periods of time, just a couple of hours (two-three) times a year, getting the same power from the grid would be much easier. • While local flexibility is highly valuable, the necessary markets, mechanisms, and systems remain underdeveloped. There is also no collected information about who has control of what, since there are many different actors involved.	• The demand for new, large-scale BESS grid connections has dropped drastically, directly correlating with the recent decline in profitability on the frequency markets.	• All batteries needs to be reported to the grid owner. (anmälningsplikt, installationsgodkännanden) • They only know the installed power of batteries and not what they are used for. If you would combine the information from grid owners with for example data from SVK on prequalified volumes it could provide a more complete picture.
12	Vattenfall. Magnus Berg. BSP and BRP, with knowledge of DSO side	• A major driver is integrating large-scale BESS directly with wind parks to optimize combined assets towards frequency and balancing markets. • Revenue in mFRR market due to more lucrative than the previous driver FCR market, however the mFRR market starts to be saturated. • There are massive financial incentives for heavy industries to utilize flexibility to drastically reduce physical imbalance costs and avoid extreme electricity price spikes.	• Long processes to get a grid connection, long response times, and a capacity limitation, affect both industry and batteries. Can take 5-7 years in worst case. • Complex regulatory and financial friction regarding who bears the physical imbalance costs when an independent Balancing Service Provider (BSP) optimizes a battery within a Balance Responsible Party's (BRP) portfolio. • The current installed capacity of stationary BESS (over 1.6 GW) already covers Sweden's total need for fast FCR services, effectively destroying the business case for new batteries relying solely on these markets. • Regulatory barriers where grid operators (monopolies) are generally prohibited from owning or operating energy storage, making pilot solutions (like the Uppsala battery) difficult to scale.	• Transitioning from 1:1 power-to-energy ratio to energy-dense systems 1:2 or 1:4 ratios, to better support energy arbitrage and mFRR. • The market focus is shifting away from fast frequency regulation toward mFRR, partly boosted by SVK's implementation of flow-based capacity calculation, and intraday energy arbitrage. • A clear move away from single-purpose batteries towards value stacking (shifting between different markets depending on current profitability). • Market focus shifts to more energy arbitrage. • Massive amounts of grid capacity, previously reserved by highly optimistic industrial projects during the green transition, are now being released back into the system as projects are cancelled, momentarily freeing up grid space. • Intraday markets are beginning to slowly take hold, although not mature yet, they may become.	• Vehicle-to-grid technology is expected to become increasingly important, with EV batteries representing a rapidly growing source of distributed battery capacity that already exceeds stationary BESS in total volume and will continue to grow significantly faster.
13	Varberg Energi Elhandel. Jens Nordberg. Energy supplier	• Varberg Energi Elhandel primary motive for investing in BESS is purely commercial, it serves to diversify the company's existing portfolio of wind and solar assets and reduce overall market risk. • The majority of large scale BESS profitability is derived from SVK's frequency markets while on small and medium-sized BESS an increasingly large share of behind the meter services tends to contribute to the profitability.	• The reliance on highly volatile daily auctions for ancillary services makes securing bank financing difficult, as banks typically require the long-term predictable revenues seen in traditional Power Purchase Agreements (PPAs). • Without stable long-term revenue agreements, securing financing for BESS is difficult. Banks are used to lending against long-term contracts like PPAs in wind power, but no equivalent exists for batteries, leaving developers dependent on volatile daily market revenues that most lenders are unwilling to accept. • The lack of standardized power tariffs across different grid areas severely complicates operations for aggregators trying to optimize batteries nationally.	• To secure stable financing, actors are developing "Hybrid-PPAs" that bundle wind, solar and BESS into a single long-term contract for industrial off-takers, creating a new, separate revenue stream for the battery. • The use of batteries have diverted from only being for the FCR-D to more other frequency markets, FCR-N, mFRR, but also energy arbitrage and other local flexibility services. • Moving forward, BESS operators will need to dynamically stack multiple revenue streams simultaneously to capture shifting flexibility values across different markets. • The expansion rate of BESS has noticeably decelerated compared to previous years due to declining profitability in the ancillary service markets.	• Reasonable to place the BESS where it can also contribute to the local grid. • Many projects were built to only contribute to SvKs markets, especially 2-3 years ago. • Local flexibility markets can get a more important role in the future. For industries or production sites this could mean that they can more quickly connect and get more power. For batteries this means another potential stream of revenue, and more importantly, a more stable one. • All batteries needs to be reported to the grid owner. (anmälningsplikt, installationsgodkännanden) • Rather than waiting for formal flexibility markets, there is a trend towards bilateral, multi-year capacity contracts with DSOs (e.g., pilots in Västra Götaland). This provides BESS owners with stable revenues while enabling faster grid connections for industries.

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Table B.1 continued from previous page

#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
14	Uniper. Henrik Pagels. Energy Industry	• Due to a dry summer 2018 and planes to phase out nuclear power, SvK needed synthetic inertia, those who could participate in FCR market were paid very well. • When FCR demands tightened, it became apparent that older hydropower plants were physically too slow to regulate the grid. This drove the "first wave" of BESS as hybrid solutions to help turbines respond faster during the initial minutes. • Extreme energy spot prices in 2022 demanded higher remuneration to attract flexibility providers, while the new FCR-D Down market was introduced to handle overfrequency, sparking massive optimism and an investment boom.	• A rapid investment boom created thousands of megawatts of battery capacity, but because the grid operator's volume needs are limited, prices have dropped to extremely low levels. • Many developers based their business cases entirely on historically high FCR revenues, making it very difficult for them to achieve profitability today. • Shifting from FCR (which requires minimal cycling) to intraday trading and mFRR requires much harder cycling, significantly increasing wear and shortening the battery's lifespan. • If grid owners invest in BESS, the batteries are not allowed to participate in other competitive markets, effectively limiting their potential. If private actors invest in BESS however, they can sell services to grid owners while also participating in other markets.	• BESS operators must pivot from purely selling capacity on the FCR market to focusing on energy volumes, intraday trading, and arbitrage (buying cheap and selling high). • To succeed in arbitrage and energy volume markets, future batteries will need longer storage capacity, shifting away from the current one-hour battery standard. • Instead of co-locating batteries with northern hydropower, a new trend is building standalone BESS in price area SE4 (southern Sweden), where energy price volatility is highest. • Batteries could increasingly be used for "black starts" (restarting a dead grid), "peak shaving" to reduce mechanical wear on other facilities, and "island mode" for local crisis preparedness and total defense. • The current over-establishment is expected to lead to a market correction where capital-strong actors buy out the struggling, unprofitable facilities.	
15	Vattenfall. Magnus Lövgren. Hydropower specialist. Team Asset Manager	• Batteries are highly effective for fast system services, such as frequency regulation. In fact, they can perform these specific tasks with a faster response time than traditional hydropower. • In certain cases, solar and wind power producers are forced to install batteries to comply with European regulatory requirements regarding frequency regulation. • The rapid expansion of wind and solar power has frequently led to production surpluses and low electricity prices. Because this reduces the incentive to build new energy production, it drives a critical need for increased system flexibility and higher electricity demand instead.	• The market is saturated from introducing more batteries which leads to less available revenue and suppressed market prices. • Batteries receive payment for delivering fast frequency responses, while the physical rotational inertia (svängmassa) naturally provided by hydropower is not financially compensated. Furthermore, batteries cannot solve the system's inertia deficit if hydropower plants are shut down due to low market prices during windy periods.	• To meet flexibility demands, a major trend will involve increasing the power capacity of existing hydropower plants, such as by installing additional turbine units. This upgrade strategy provides a form of flexibility similar to batteries, allowing for more power generation at the right times without altering the total energy production volume, but with the significant advantage that hydropower can operate and provide value over much longer time scales than BESS.	• Battery energy storage is inherently limited to short time scales, generally functioning effectively from seconds up to hours. They are not equipped to handle long-term storage needs, such as storing energy for weeks to balance prolonged wind power variations. • Placing batteries in direct connection with hydropower plants provides no unique advantage to the overall grid, as batteries could be placed anywhere else. The argument that batteries reduce mechanical wear on hydropower turbines is economically insufficient to justify the investment. • The industry must step back from focusing exclusively on batteries and instead evaluate the electricity system as a comprehensive whole. Batteries will increasingly be viewed as a short-term complement rather than a standalone overarching solution. • There is a strong theoretical push to establish dedicated markets for rotational inertia (svängmassa). Creating these market incentives is viewed as far more effective than imposing strict technical requirements that generate costs without yielding any revenues.

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#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
16	Energimarknadsinspektionen. Marielle Lahti. Supervisory authority	• Battery projects can reach maturity and be ready for grid connection much faster than other types of infrastructure. • Batteries that can demonstrate clear benefits for the local or regional grids where they connect are more likely to be viewed as system assets rather than grid burdens, which could in turn facilitate smoother connections and broader acceptance.	• Because BESS projects mature so quickly, they can rapidly claim available grid connection capacity, potentially pushing out other vital societal electrification projects like industries, schools, and transport. • Currently, BESS primarily provides system benefits upwards to the national grid operator (Svenska kraftnät) and does not always create tangible benefits for the local or regional grids where they are physically connected. • Conditional grid contracts are restricted, and require a proven capacity shortage, need Ei's approval for the methodology with which it was made, and can only be temporary while waiting for physical grid expansions. • Sweden's grid sector operates with over 170 grid owners each setting their own tariffs and contract models under a permissive regulatory framework. A new tariff regulation was due to take effect in January 2027 but will be revoked following a government task requiring EI to restart the process.		• They have no data on BESS. • Svenska kraftnät is exploring a zoning concept where different regions in Sweden would have allocated grid capacity for specific types of customers, potentially establishing BESS as its own distinct category. → releases 30th April.
17	Volvo Group. Staffan Rödjedal. Sustainability/automotive	• For industries and transport operators, BESS enables peak shaving, reducing the need for costly high-capacity grid connections and lowering subscription costs. • Participation in SvK's frequency markets provides an additional revenue stream for battery owners in the transport sector, though this must be balanced against operational availability requirements, such as securing power to safeguard productivity of electrified transport.	• The logistics sector requires extremely high battery availability to meet vehicle schedules, creating a conflict of interest with the desire to maximize revenue on SvK's frequency markets, where the battery may not be fully charged when needed for charging trucks. • Large-scale off-grid operation for charging of commercial vehicles is not practically nor economically feasible, as it would require significant oversizing of solar and wind and batteries capacity to guarantee sufficient power availability at all times. • Unplanned truck-charging during price peaks can generate extreme imbalance costs, for example where the electricity itself costs 2,000 SEK but the associated imbalance cost could reach 50,000 SEK at extreme levels. • Distributing imbalance costs out to individual charge points would create unmanageable risks for the logistic sector and charge point operators. It is more efficient for society to manage deviations at a higher system level where fluctuations can offset each other.	• The market has shifted from FCR as the dominant revenue source toward mFRR, reflecting broader changes in the ancillary services market. • Imbalance costs have increased by a factor of approximately five following SvK's decision to dedicate transmission capacity between price areas to the day-ahead market, forcing SE3 and SE4 to manage intraday imbalances using their own local resources, where large-scale hydropower is largely absent. • Intraday market prices have risen dramatically, from around 50-100 EUR/MW to over 1,000 EUR/MW, with SvK reportedly considering a ceiling of 10,000 EUR/MWh. • The introduction of PICASSO, connecting the Swedish intraday market to a European platform, is expected to bring significant further changes to the market, the full consequences of which are difficult to predict.	
18	Svenska Kraftnät. Oscar Jonsson, Alicia Lööf. TSO	• EU directives about an independent BSP → this could open up the market and allow smaller actors to also become BSP more easily. • A changing production mix and increased electrification drives an increased need for balancing markets and ancillary services.	• The current requirement for actors to hold BRP status in order to act as BSP is resource-demanding and creates a significant barrier to market participation for smaller actors. • The changing production mix creates challenges such as volatile prices. • There is a challenge in securing a sufficient supply of ancillary services in bidding zone SE4.	• The market is moving towards a separation of the BSP and BRP roles, and transitioning to 15-minute settlement periods.	• There is Nordic cooperation in implementing EU regulations. • When PICASSO is introduced in Sweden it is expected to have an impact in the market, possibly increasing the demand of aFRR. • If you have >10MW, you would pre-qualify all assets since you don't necessarily need to bid with all power. • FCR-D down, is dimensioned for the biggest possible electricity issue in the grid, in this case one of the largest international cables. • Batteries are usually classified as LER (Limited Energy Reservoir) - technical requirements associated with FCR for example. • For FCR you are only allowed to prequalify 80% of the total capacity.

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#	Organisation, Name, Actor Type	Drivers	Barriers	Trends	Other information
19	Energimyndigheten. Klara Bjerndal & Johan Harrysson. Authority				• Underreporting risk: The official statistics may be underreported, particularly for smaller systems, because reporting practices among installers are inconsistent. • No regional breakdown + publication lag: The data is only aggregated at the national level (no breakdown by bidding zone) and isn't published until roughly ten months after the reporting period ends.

C

Appendix C

This Appendix shows the AI prompt that was used to summerise the transcripts from the interviews.

Step 1 – DETAILED:
I will upload a transcribed interview.
I want a summary with everything [person's name] says in a very detailed, coherent text.
Important:

- Write in continuous text (not bullet points)
- It should feel like a carefully retold account of everything the person says
- Don't miss anything—include tangents, examples, and reasoning
- Structure the text into paragraphs by theme, but without bullet points
- Keep the content as close to the original as possible, but in a polished form
- Do not create your a own analysis of the material

Focus only on what [person's name] says, not the interviewers (Ida and Pontus).

Step 2 – OVERVIEW (bullet points):
Now create a more summarized version of the same content.
Use:

- Headings
- Bullet points
- Thematic structure

Important:

- Include all key points
- But make it more concise and easy to understand

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS
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www.chalmers.se

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