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Charging ahead: An evaluation of BESS in DB Schenker's electrification journey

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Abstract

As the electrification of vehicles progresses in Sweden, logistics providers can face difficulties in ensuring a reliable power supply for charging their fleets. This study explores the feasibility, business case and implementation process of battery energy storage systems (BESS) as a potential solution to support the electrification journey. The research focuses on the context of DB Schenker and takes a qualitative approach with a wide data collection primarily stemming from interviews with 19 participants. A quantitative case analysis is also conducted on three selected distribution terminals to investigate the impact of various preconditions on the overall business case. The findings illustrate the current landscape for BESS and the business network of necessary actors, resources and activities involved in an implementation. This network is characterized by a lack of clear regulatory guidance and a complexity stemming from the interconnectedness and changing roles of actors. For the business case, while participating in balancing markets currently offers a lucrative revenue stream, uncertainties persist regarding future revenue generation. The study also identifies several factors influencing the feasibility of BESS implementation such as the current grid connection or usage patterns of electricity. The managerial implications emphasize a need for strategic collaboration and developing knowledge while the policy implications call for increased regulatory guidance to enable more standardized best practices.

Keywords: Electrification, Distribution terminal, BESS, Energy storage, Logistics, Sustainability, Grid connection.

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Ella Sibbmark and Tamás Nagy, Gothenburg, May 2024

List of acronyms

EU	European Union
BESS	Battery Energy Storage Systems
BMS	Battery Management Systems
EMS	Energy Management Systems
SvK	Svenska kraftnät
FCR	Frequency Containment Reserves
FCR-D	Frequency Containment Reserves for disruptions
FCR-N	Frequency Containment Reserves for normal operations
FFR	Fast Frequency Reserves
FRR	Frequency Restoration Reserves
aFRR	Automatic Frequency Restoration Reserves
mFRR	Manual Frequency Restoration Reserves
INA	Industrial Network Approach
EV	Electric Vehicle
V2G	Vehicle to Grid
SoC	State of Charge

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1. Introduction

In the coming years, Sweden, Europe and the global community are all subject to drastic changes to facilitate a continued decarbonization to support the set United Nations' sustainable development goals (United Nations, 2023). The transportation sector is one of the major contributors to the greenhouse gas emissions, accounting for over 20% of the total global carbon dioxide emissions (Tiseo, 2024). Road transportation in particular is responsible for 76% of all greenhouse gas emissions caused by transportation in the European Union (EU) in 2021 (European Environment Agency, 2023). To address this issue, EU set a target in 2019 to reduce the road transport carbon dioxide emissions from new heavy-duty vehicles by 15% until 2025 and with 30% until 2030, compared to the baseline year 2019 (European Union, 2019). The implementation of emission rights is one of multiple ways EU uses to aim for the objective, and a new emission rights trade for road transports will be in place by 2027 (Naturvårdsverket, 2023).

With electrification in the forefront, industries and logistics actors are scrambling to replace greenhouse gas emitting machinery with electrified alternatives. In Sweden alone, this transition means an increase in electricity consumption to a projected 310 TWh by 2045, a significant leap from the previous 153 TWh in 2023 (Lejestrand, 2021; Statistiska Centralbyrån, 2024). Not only does the energy production need to double, but more than 100 TWh of Sweden's current electricity sources are nearing the end of their lifespan demanding extensive investments in new renewable energy sources (Energimyndigheten, 2019).

Currently, the Swedish energy mix consists predominantly of hydroelectric power, nuclear power and wind power (Energimyndigheten, 2021). The share of wind power in particular is growing and has increased from 11% to 17% of the total Swedish energy mix during 2020 alone (Energimyndigheten, 2021). Similarly, the output from solar power has almost doubled year-over-year during the last decade (Energimyndigheten, 2023). However, the intermittency of these emerging power sources means that there is an increased need to re-evaluate how energy is stored, managed, and distributed over the grid to accommodate the dynamic fluctuations of both supply and demand (Svenska kraftnät, 2021a).

Among the emerging alternatives for addressing the dynamism in supply and demand of electricity are Battery Energy Storage Systems (BESS) (Hannan et al., 2021). BESS enables actors to decrease their peak electricity demands from the power grid but also a decoupling of the point of purchase from the point of consumption. Ongoing advancements in this area have not only led to significantly increased battery cell capacity but it has also resulted in lowered prices that make these systems increasingly viable for large scale development (Ziegler & Trancik, 2021).

DB Schenker stands as a proactive actor in the mission towards decarbonization, aiming to achieve climate neutrality by 2040. Electrifying large parts of the current vehicle fleet is a significant element of DB Schenker's transition to fossil free transports. By 2030, they aim to electrify 100% of the electric parcel trucks and 60% of all vehicles under 18 tonnes. This endeavour requires not only significant infrastructure development but also demands economic sustainability in the firm's electrification initiatives. Hence, DB Schenker has tasked the authors of this report to investigate the feasibility to adopt BESS for their distribution terminals to help with their electrification efforts.

1.1 Purpose and research questions

The purpose of this study is to explore the feasibility and implications of integrating BESS within Swedish distribution terminals with the objective to gain resilience against grid shortages and allow for a continued electrification. Based on this purpose, the following research questions have been developed:

RQ1: How could BESS be implemented in a distribution terminal setting?

RQ2: What is the business-case for BESS in distribution terminals today and in the future?

RQ3: Under what circumstances is it feasible to implement BESS in distribution terminals?

The research questions were derived to help explore the BESS landscape and to understand the practical aspects of an implementation. Furthermore, the research questions were formulated to evaluate the economic viability of BESS as well as to understand which contextual factors and conditions that can impact the feasibility of implementing such systems.

2. Method

Explorative research is suitable when studies are conducted into a phenomenon in a less established environment (Forza, 2002). Investigating BESS in the context of logistics providers has not yet been widely studied to the knowledge of the authors, making an explorative approach appropriate for this study. The explorative nature can also provide preliminary insights, laying the foundation for future researchers who aim to investigate single aspects of the matter more in-depth (Forza, 2002). Furthermore, a qualitative methodology has been used in the form of a case study in order to allow for an extensive investigation of the specific setting (Bryman & Bell, 2007). Some quantitative aspects have also been considered to supplement the qualitative findings and provide a more comprehensive picture.

The study began with a pre-study and was followed by an extensive data gathering through a broad range of data sources. These included interviews, quantitative internal data from DB Schenker, three study visits at DB Schenker's distribution terminals as well as participation in an internal energy strategy meeting. Finally, all collected material was analysed and a conclusion was formulated based on the findings from the research. Each of the main areas are explained in more detail in the remainder of this chapter.

2.1 Case company description

DB Schenker is a global logistics provider in the DB Group. The company mainly consist of three lines of business: *Land transport, Air and ocean freight* and *Contract logistics*. In the Nordics, DB Schenker employs over 6000 people and has a yearly revenue of around 3 billion Euro. In 2022, a program was initiated in DB Group to drive transformation in the areas of market expertise, corporate sustainability, work culture, digital and process excellence, and economic strength. They have also set a target to become climate neutral by 2040, and a major way of achieving this objective is by electrifying their fleet of vehicles. Furthermore, DB Schenker has committed to reduce their carbon emissions for all European land transports by 50% in 2030 compared to 2022.

The electrification journey at DB Schenker is already ongoing. For example, previous projects have been carried out to invest in charging infrastructure, as well as pilot projects in collaboration with other companies to develop electric long haulage transports. Efforts are also made from partnering haulage companies who are also striving to electrify their vehicle fleets.

2.2 Pre-study

A pre-study was done initially with the purpose of giving the authors a better understanding of the context in which the research was being done. It was also performed to identify the major focus areas for the study, as well as aspects to exclude from the research scope. To reach these goals, five interviews were carried out with different actors within DB Schenker, see Table 1 below. In the report, they are referred to as Respondent 1–5, in random ordering to preserve the anonymity of the individuals. As the question of BESS has seen attention from the entire

Nordic region, the Finnish and Danish business units have already started to investigate the matter, for why they were chosen as participants in the pre-study.

From the interviews in the pre-study, it was concluded that it is necessary and valuable to focus the study on a few terminals rather than covering all terminals in Sweden. This is due to large differences for the currently active terminals where each of them has unique characteristics. To determine what terminals to focus on, the maximal variation sampling method was used, which aims to highlight variations in the studied phenomena (Øvretveit, 2001). In this case, a previous project within DB Schenker was available that highlighted the ability of each Swedish terminal to fully electrify their fleet with today's conditions. From that report, three terminals were chosen that scored low, high, and intermediate respectively regarding the ability to electrify, referred to in the report as terminal A, terminal B, and terminal C. Another finding from the pre-study was that the economical aspect of the BESS was highly central for all parts of the organisation. Thus, certain emphasis has been directed towards the economic factors of an implementation of BESS.

Table 1

List of interviewees in the pre-study phase, and the reason they were chosen.

Role	**Relevancy for pre-study**
Real Estate Manager at DB Schenker Finland	To explore the Finnish organization's assessment of adopting BESS and to explore the considerations involved, as well as the potential challenges they might have encountered this far.
Real Estate Officer at DB Schenker Denmark A/S	To explore the Danish organization's assessment of adopting BESS and to explore the considerations involved, as well as the potential challenges they might have encountered this far.
Head of Innovation and Purchasing at Schenker Åkeri AB	To better understand the electrification journey at DB Schenker, as well as the future need of electric vehicles and important aspects in the procurement process of innovative technologies.
Property Manager at DB Schenker Property Sweden AB	To gather information about how the terminals operate, what possible limitations exist for the implementation of BESS and to gain access to quantitative data on consumption patterns of electricity.
Specialist at DB Schenker Sweden AB	To better understand how the terminals operate, what possible limitations exist for implementation of BESS and to gain access to quantitative data on vehicle movement patterns.

2.3 Interviews

Semi-structured interviews with different stakeholders have been conducted. The interviews provided the benefits of allowing the interviewees to more freely construct their responses while reaching a discussion with wider range compared to questionnaires (Valentine, 2013). The semi-structured nature also allowed the interviewers to develop follow-up questions based on previous responses, resulting in more flexibility (Kallio et al., 2016).

Interview guides were prepared and used during each interview to help guide the interview towards the intended areas. The questions used in the interview guide were of different character to include various angles of the topic to explore, which is in line with what Valentine (2013) recommends. This includes descriptive questions about experiences and activities, as well as thoughtful questions to understand the interviewees own opinions. Most questions in the interviews were of an open nature, as this does not impose a particular answer or limits the interviewees answer (Valentine, 2013). When permission was given from respondents, the interviews were recorded and transcribed. This comes with advantages such as getting a more accurate representation of the answers provided as well being able to be more present during the actual interview (Valentine, 2013). Also, according to Braun and Clarke (2006) transcribing the data is a great way of familiarising yourself with the data collected, which is the initial activity when conducting a thematic analysis, described in more detail in chapter 2.5.

The interviewees were initially found within DB Schenker's organisation based on their roles. The objective was to reach persons with different perspectives, ranging from terminal experts to electrification experts amongst others. Apart from the initial interviewee sample, the snowball sampling method was used to identify further interviewees based on other respondents' recommendations. This method is commonly used to find knowledgeable people within certain fields (Øvretveit, 2001). Apart from internal interviews at DB Schenker, it was also of interest to reach solution providers for battery energy storage systems to gather expertise of the solutions that may not be found within DB Schenker. After the initial interviews, several other actors emerged as important future respondents for the report.

Identification of new interviewees continued until the data saturation arose. This usually occurs when patterns appear in the data and new interviews no longer provide new information and instead repeat data that is already collected (Fusch Ph D & Ness, 2015). For this report, overall data saturation was observed during the last two interviews, where most topics had already been discussed with prior respondents. The level of saturation occurred at different stages for the different types of actors which led to some type of actors requiring more interviews in total. An overview of interviews is found in Table 2 below.

To respect the integrity of the respondents and their respective company, no names of interviewees, nor any company is mentioned in the report, which is the most common way of anonymisation (Saunders et al., 2015). Offering anonymity can be essential for the interviewees to feel safe in revealing opinions and statements (Gibson et al., 2013). To still provide value to the reader, the type of actor has been included. This is to show the width of the data collection, but it is also relevant since different types of actors may naturally have different opinions, biases, and viewpoints. A complete list of respondents is seen in Table 2 below.

Table 2

Overview of interviewees

Current role	Type of Actor	Respondent
Interviewee from pre-study	Case company	1
Interviewee from pre-study	Case company	2
Interviewee from pre-study	Case company	3
Interviewee from pre-study	Case company	4
Interviewee from pre-study	Case company	5
Head of Sales	Large BESS provider	6
Manager	Case company	7
Senior project manager, R&D	Energy provider	8
Product Marketing Specialist	Large BESS provider	9
Co-owner and Chief of Sales	BESS provider	10
Key Account Sales Manager	Grid owner, BESS provider and Energy provider	11a
Senior Business Developer	Grid owner, BESS provider and Energy provider	11b
Manager	Case company	12
Sales Expert in Flexibility Management	Energy provider and Aggregator	13
Business Developer	Aggregator	14
Head of Technology	Grid owner	15
Key Account Manager	Aggregator	16
Key Account Manager	Energy provider and Aggregator	17a
Business Developer	Energy provider and Aggregator	17b

2.4 Additional data collection

According to Yin (2009), the findings in a study are likely to be more convincing and accurate if being based on several sources of information. In line with Yin (2009), this study incorporates a diverse range of data sources to ensure that comprehensive and correct findings can be made. The different data that have been used stem from previous literature, interviews, and data from various internal sources.

A literature review within the relevant fields was conducted with the aim of describing existing knowledge within the topic. Search engines such as Google Scholar and Scopus were used to find relevant articles. Keywords that were initially used include among others *battery energy storage systems, BESS logistics, grid balancing, peak shaving,* and *energy storage Sweden.* These words were used separately or in combination. As the study continued, new keywords arose and developed, such as *balancing services*, *balance responsible* and *local flexibility markets.* All articles used for this literature study have been critically reviewed to get an understanding of the purpose, origin and credibility of the papers, in line with recommendations from Linnaeus University (2021).

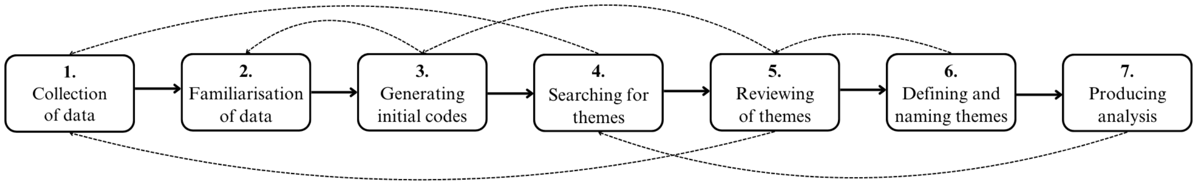
The data collected from internal resources include DB Group's and DB Schenker's webpages and their annual reports, data available at DB Schenker Consulting and data from DB Schenker's supplier of electricity. For example, data from previous DB Schenker projects have been collected consisting of the usage patterns of their existing fleet as well as information regarding the electric infrastructure and capacity of the chosen case terminals. This data has been consolidated and is utilized in the calculations performed in the analysis chapter. The terminals have been anonymised after a dialogue with DB Schenker as this report will be publicly published. Additionally, three study visits to selected DB Schenker terminals were performed to better understand the operational activities and the context of which the firm operates in. Lastly, data for this report was also gathered through attendance at meetings, such as one pertaining to DB Schenker's energy strategy.

2.5 Thematic analysis

To analyse the gathered data from the interviews a thematic analysis was conducted. Thematic analysis is used to identify patterns across data in a structured way and the method was chosen primarily due to its flexibility (Clarke & Braun, 2017). The coding of data was done inductively, meaning the data was used as a basis for coding and developing themes rather than the deductive approach where existing theoretical concepts are used to develop themes (Terry et al., 2017). Furthermore, the coding was done semantically, focusing on what the interviewees actually said instead of the latent coding where underlying meanings are interpreted (Terry et al., 2017). The six step guide on how to conduct a thematic analysis developed by Braun and Clarke (2006) was followed. However, the process was not as linear as Braun and Clark's process may appear. Rather it followed the theory of systematic combining developed by Dubois and Gadde (2002). They realized the need of an iterative process where the researchers can go back and forth between various steps, as empirical findings cannot be fully understood without theory and vice versa. With these two theoretical frameworks in mind, a process developed where the six steps from thematic analysis were followed, but not necessarily strictly linearly. Instead, later steps could for example trigger new data gathering, as shown in Figure 1.

Figure 1

Visualisation of the process from data collection to the analysis.



Note. Adapted from Braun and Clark (2006) and Dubois and Gadde (2002).

3. The what, why and how of BESS

In Sweden, electricity is transported through a power grid that is composed of three parts (Svenska kraftnät, 2022c). The transmission grid is the backbone of the whole system and spans the entire length of the country, directly connecting the largest producers to the national grid. Regional grids connect to the transmission grid to producers, large consumers of electricity as well as the local grid which is used to connect the small consumers and individual households of Sweden.

For the national grid to function as intended, there must at every instance be an equal production of electricity as there is consumption. As it is impossible to exactly predict consumption and production of electricity, there needs to be reserves that can compensate for the deviations that occur. BESS is one such reserve that can both be utilised to absorb excess energy and to contribute with additional power during peak demand periods. Currently, there are several monetary incentives in place to make actors want to contribute to the stability of the grid. This chapter aims to provide information to the reader regarding the main concepts explaining what BESS are, how the systems can be used to balance the national grid but also describe why one might want to engage in such activities.

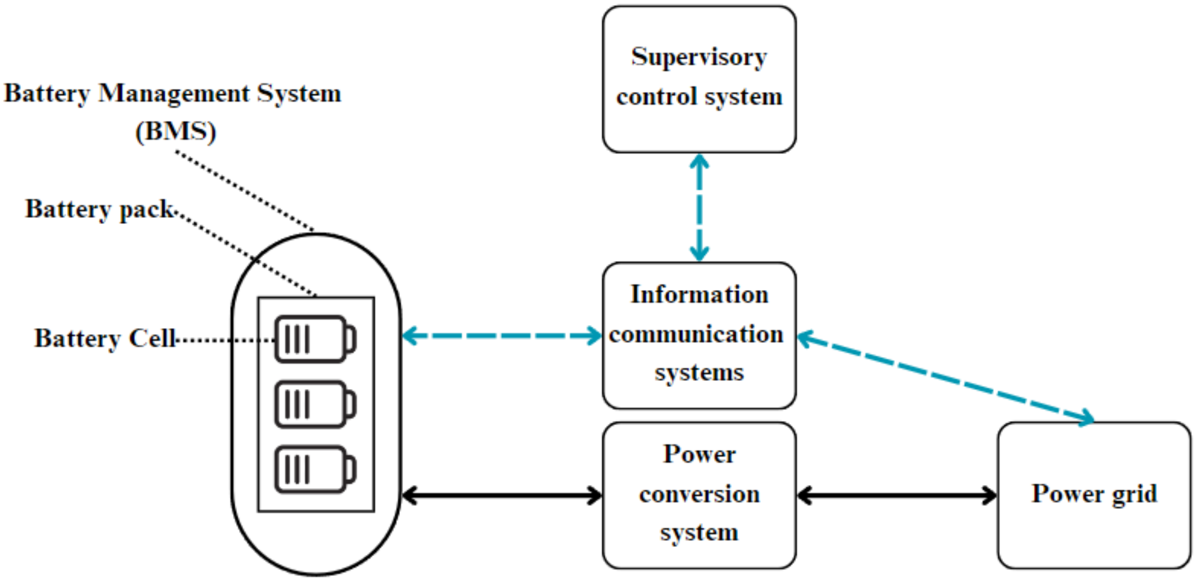
3.1 Battery Energy Storage Systems

Historically, the significant cost of energy storage has often meant that construction of excess production capacity have been preferred to the alternatives to store energy (Lawder et al., 2014). However, BESS have seen significant growth thanks to advancements in efficiency and energy density (Lawder et al., 2014), but also due to the low response time that the technology enables (Chatrung, 2019). In the contemporary electric systems, BESS serve several purposes such as improving the grid stability, reducing the source intermittency and matching peak power demand (Lawder et al., 2014).

The systems are generally made up from five main components that can be seen in Figure 2 and include: One or many battery packs, a battery management system (BMS), power conversion systems, information communication systems and a supervisory control system (Hidalgo-León et al., 2017). There are multiple chemistries that are used in BESS applications, including lead-acid batteries, sodium-sulphur batteries and lithium-ion batteries (Chatrung, 2019). Each battery chemistry is characterized by technical limitations when it comes to discharge-rate, energy density, life span, discharge rate and so on. Lithium-ion batteries are currently the most common technology due to its overall flexibility with a high efficiency, high life span, low discharge rate and rapidly decreasing costs (Chatrung, 2019; Collath et al., 2022). Individual battery cells are connected either in a parallel or a serial combination to form the battery packs in the BESS (Hidalgo-León et al., 2017).

Figure 2

Simplified schematic overview of components in a conventional BESS.



Note: Dashed arrows represent information flow and solid arrows represent flow of electricity. Adapted from Hidalgo-León et al. (2017) and Lawder et al. (2014).

To control and monitor the battery packs in the BESS, a BMS is used (Lawder et al., 2014). By accessing key sensory information from the batteries, the BMS can make decisions in how to control the systems to ensure maximal performance and a prolonged lifespan (Lawder et al., 2014; Xing et al., 2011). Temperature regulation is one of the BMS's main functions due to its importance for the overall safety, efficiency, and life expectancy of the BESS (Chatrung, 2019; Rahimi-Eichi et al., 2013). Operational efficiency is also positively affected as temperature correlates with the internal resistance in the battery unit (Rahimi-Eichi et al., 2013). Apart from temperature regulation, a BMS is also responsible to ensure that the battery pack stays within voltage limits, determines the state of charge and also controls so that the BESS is shut down in case of malfunctions in the system (Lawder et al., 2014). A challenge with BMS is the requirements when it comes to computational power that is required to run the complex algorithms needed for various activities that the BMS perform (Xing et al., 2011).

Power conversion systems are the components used to convert alternating current from the power grid to direct current which is the form in which electricity is stored in the battery packs (Hidalgo-León et al., 2017). How much electricity is discharged or charged to the battery is in turn determined in real time by the supervisory control system, sometimes referred to as the energy management system (EMS). The communication between different parts of the system such as the BMS and the grid is done by information communication systems that let the supervisory control system manage the functionality of the BESS (Lawder et al., 2014).

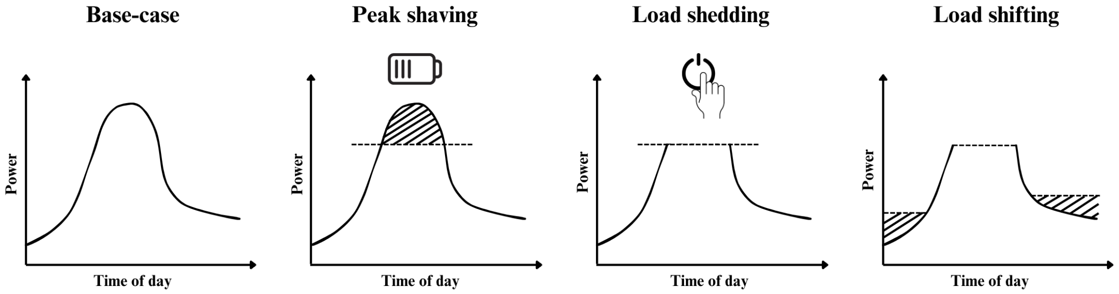
3.2 Peak demand management methods

The energy demand patterns vary over time and include peaks significantly higher than the average demand. Traditionally, a way to overcome these peaks is by adding generators that run for short durations to temporarily increase the power output. However, this results in several disadvantages such as low utilisation, higher CO2 emissions, faster deterioration of equipment and higher fuel consumption (Uddin et al., 2018). Due to these disadvantages, energy providers often charge an extra premium based on the customer's peak demand level in order to incentivise a more evenly distributed demand (Chua et al., 2016). These costs, called power tariffs, will become mandatory for all the Swedish grid companies to include in their cost model by the start of 2027 to incentivise consumers to spread their energy consumption more evenly throughout the day (Energimarknadsinspektionen, 2022). For the energy consumer, also referred to as the demand side, there are different ways to adjust their energy consumption to reduce the overall peak demands, including peak shaving, load shedding and load shifting (Chua et al., 2016; Sun et al., 2013).

Peak shaving consists of various strategies to eliminate the peaks in an electricity distribution system without changing the consumption pattern (Rahimi et al., 2013). One way to achieve that is by using BESS to reduce the output needed from the grid in times of peak demand by drawing energy from the batteries rather than the grid (Rahimi et al., 2013). *Load shedding* refers to efforts being made to reduce peak demands for example by turning off non-essential electricity consuming devices, such as lamps or heaters (Sun et al., 2013). This method can be based both on priority rules and statistics. Finally, the third option is the *load shifting* method, which instead focuses on rescheduling energy demanding activities during peak hours to off-peak hours (Sun et al., 2013). An overview of the mentioned techniques is seen in Figure 3.

Figure 3

Visualization of peak demand management methods.



Benefits of the mentioned peak demand management methods extend to both grid operators and end-users but can also result in an overall reduction in CO2 emissions (Uddin et al., 2018). However, crucial for the success of these methods is according to Uddin et al. (2018) to have a sufficient monetary incentives for actors to be willing to adjust their normal activities and to be willing to invest in the required equipment and infrastructure needed.

3.3 Balancing services

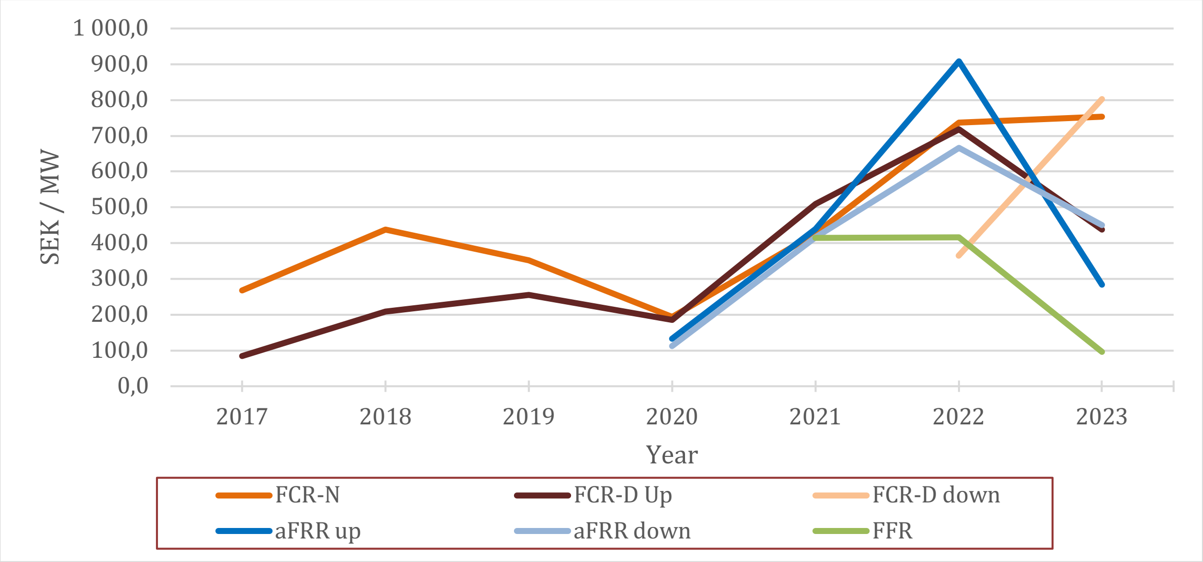
In Sweden, Svenska kraftnät (SvK) is the main actor responsible for balancing supply against demand to ensure stability in the power grid (Svenska kraftnät, 2021a). Stability in this context entails keeping the overall grid frequency at 50.0 Hz by ensuring that the production in each instance corresponds to the actual usage (Svenska kraftnät, 2021c). A stable frequency is important to ensure optimal operation of equipment connected to the grid. To their help, SvK utilises balancing actors who are responsible for adjusting their production according to the forecasted consumption of electricity. Each supplier of electricity must according to law take responsibility to balance the grid and must appoint external firms if they cannot themselves contribute as a balancing actor (Svenska kraftnät, 2021b).

Furthermore, to handle short term variations during the day, SvK makes use of three main balancing services with a total volume of around 2 GW (Svenska kraftnät, 2024c). As these services are market based and subject to competitive bidding, they enable a new revenue stream for firms looking to contribute to the stability of the grid (Svenska kraftnät, 2021c). Previously, one could only offer balancing services either by being a balance responsible party or by entering into agreement with one such actor. As of May 2024, SvK is introducing a new role to enable market actors to act as a balancing service providers for certain balancing services without having the balancing responsibilities (Svenska kraftnät, 2024d).

During 2023, SvK procured balancing services for 6.9 BSEK, a stabilisation of the substantial increases during the year before (Svenska kraftnät, 2024a). In their annual report SvK mention a rise of 10% in supply across many of the balancing markets with batteries and wind power increasing the most. The average historical hourly price per cleared volume for each of the balancing services can be seen in Figure 4 below and a detailed explanation of the different services will follow.

Figure 4

Hourly average compensation for balancing services 2017-2023



Note: The prices represent the hourly averages for each year. Compensation for energy use is not included. For aFRR, an average is used only for those hours where bids have been cleared. Compensation for FCR-N, FCR-D and aFRR have been converted from EUR to SEK according to currency exchange rates as per 20 March 2024. From Svenska kraftnät (2024f).

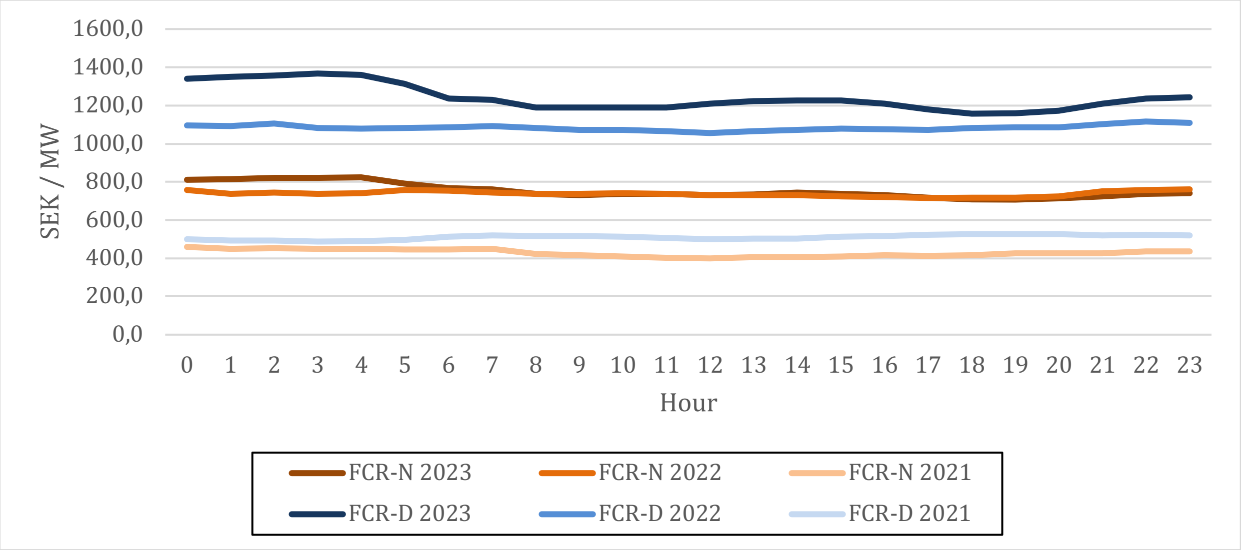
3.3.1 Frequency Containment Reserves

Frequency Containment Reserves (FCR) are one of three balancing services with the purpose of quickly stabilising the grid frequency automatically in the case of imbalances (Svenska kraftnät, 2023b). FCR are divided into two products, namely FCR-N for normal operation and FCR-D for disturbances. FCR-N is activated when the grid frequency deviates to a range between 49.9–50.1 Hz. The capacity for FCR-N procured by SvK for 2024 is 235 MW where balancing actors can bid in intervals of 0.1 MW (Svenska kraftnät, 2024b). Bids are symmetrical, which entail that they are offered for both up- and downregulation. The compensation for actors contributing with FCR-N is partly a remuneration for the capacity provision, and partly for the utilised energy required to provide the service. However, Khodadadi et al. (2020) highlight that the activated energy is often small, meaning that the majority of the turnover for the balancing actors comes from the capacity provision.

FCR-D is activated when there are disturbances in operations and when the frequency reaches a range between 49.5–49.9 Hz or 50.1–50.5 Hz (Svenska kraftnät, 2023c). As opposed to FCR-N, bids are not symmetrical for FCR-D, and they are instead divided into FCR-D upregulation and FCR-D downregulation respectively. The national capacity requirements for these services for 2024 are 567 MW for up- and 547 MW for downregulation with a minimum bid size of 0.1 MW (Svenska kraftnät, 2024b). Resources used for this service must sustain the load of the accepted bid for at least 20 minutes. A difference when compared to FCR-N is that FCR-D providing actors only receive compensation for the capacity provision but not the energy used to provide the service. The compensation for the capacity provision between the years 2022–2023 can be seen in Figure 5.

Figure 5

Hourly averages for the remuneration of capacity provision for Frequency Containment Reserves 2021–2023.



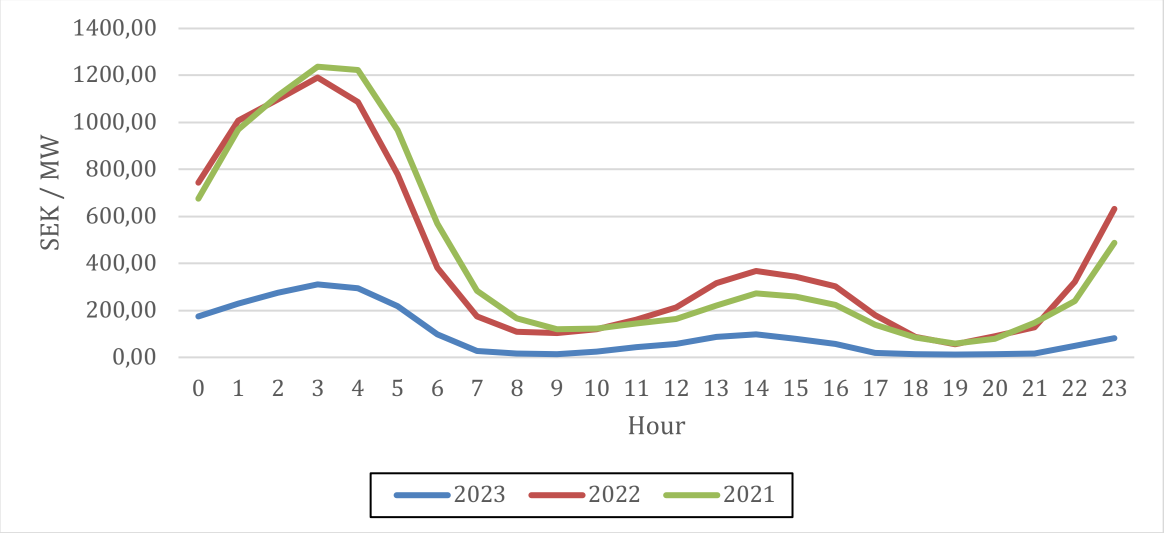
Note: The compensation for energy used in FCR-N is not included. The numbers used for FCR-D is a sum of both up- and downregulation. The numbers have been converted from EUR to SEK according to currency exchange rates as per 20 March 2024. From Svenska kraftnät (2024f).

3.3.2 Fast Frequency Reserves

Rotating generators are often used in power systems to store rotational energy in order to avoid outages in situations of power plant failures (Denholm et al., 2020). Fast Frequency Reserve (FFR) is a Nordic initiative since 2020 that has the purpose of providing fast responses to low-inertia situations in the Nordic grid when there are low amounts of rotational energy available in the system (Svenska kraftnät, 2024e). SvK procures a volume of around 100 MW of FFR through a public tendering process where winners receive yearly contracts (Svenska kraftnät, 2023a). Remuneration for these services is based on the capacity cleared but there is no remuneration for the energy used during activation. Average hourly compensation over the last three years can be seen in Figure 6.

Figure 6

Hourly averages for remuneration for Fast Frequency Reserves 2021-2023.



Note. From Svenska kraftnät (2024f).

To be able to partake in the FFR market, participants must not be balancing actors but they have to be prequalified to ensure that they meet all necessary requirements (ENTSO-E, 2021). For example, systems should have activation time of between 0.7–1.3 seconds and a total support duration time of either 5 or 30 seconds. Systems should also be ready for reactivation within 15 minutes of a previous activation. Other than the solely technical requirements, there are also specifications that need to be met in terms of documentation and cyber security (ENTSO-E, 2021).

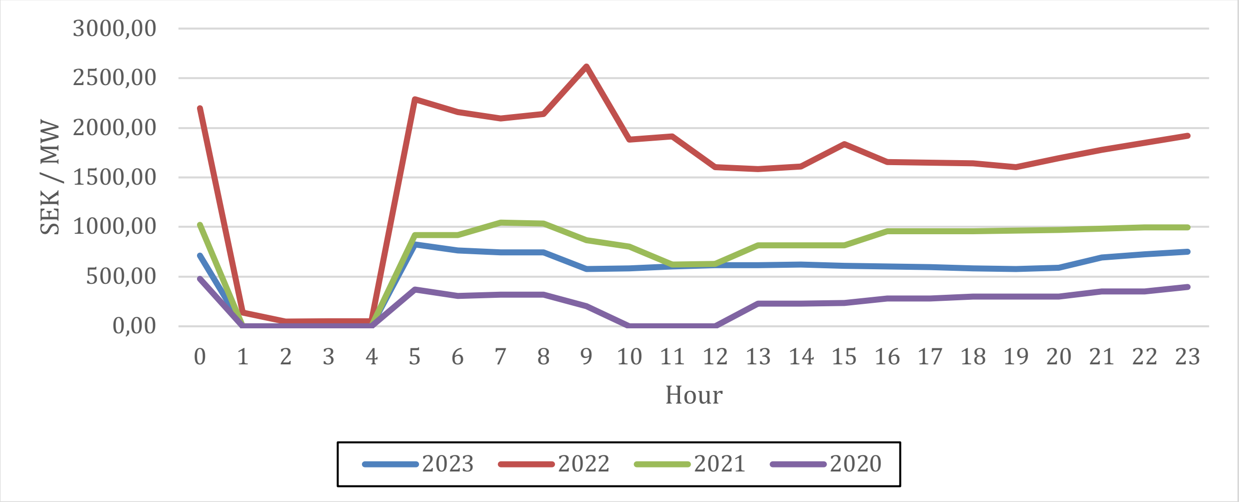
3.3.3 Frequency Restoration Reserves

SvK currently employs two products for Frequency Restoration Reserves (FRR) which are automatic frequency restoration reserve (aFRR) and manual frequency restoration reserve (mFRR). aFRR was according to Khodadadi et al. (2020) developed as a response to declining frequency stability where the product was deemed to have a high potential due to the fast response rate relative to the more traditional mFRR. The main difference of FRR when comparing it to FCR is that FRR is centrally controlled instead of being done locally. Furthermore, the two services communicate with each other where FRR works to regain an optimal frequency in the grid while FCR stabilizes the frequency.

SvK's forecast of the required volume of aFRR is estimated at 106 MW for upregulation and 111 MW for downregulation for 2024 (Svenska kraftnät, 2024b). The forecasted demand for mFRR is 300 MW for both up- and downregulation. Actors wanting to participate in the aFRR market must ensure that their equipment can reach 100% of their bid volume within 5 minutes and have the endurance of one hour. The bid size for aFRR is a minimum of 1 MW whereas mFRR requires a minimum bid of 5 MW. Activation of mFRR reserves are done on requests by SvK where actors must reach 100% of their volume commitments in the bid within 15 minutes and have a total endurance of 1 hour (Svenska kraftnät, 2023d). Remuneration for aFRR and mFRR is provided for both capacity provision as well as energy usage, although capacity provision for mFRR have only existed since 2023. Average hourly compensation for capacity provision over the last four years for aFRR are shown in Figure 7.

Figure 7

Hourly averages of the remuneration for capacity provision for Frequency Restoration Reserves 2020–2023.



Note. Only capacity remuneration is considered. The numbers used in the figure is a sum of both upregulation and downregulation of aFRR. From Svenska kraftnät (2024f).

3.3.4 Local flexibility markets

Apart from national balancing markets, local markets are also developing. As of today, SvK partakes in two research projects, where the first one is initiated and financed by EU for three countries, and the other one is about increasing the flexibility in the Stockholm area of Sweden (Svenska kraftnät, 2022b). These local flexibility markets are coordinated with, and complements the existing national market (Svenska kraftnät, 2023e). For example, in the EU project, named CoordiNet, local capacity in Malmö that is not used to handle local bottlenecks will be sent to participate in SvK's national mFRR market (Svenska kraftnät, 2022a). The chosen locations for these demonstrations all have different issues and preconditions. For some places there are increasing demand for power, while others struggle with having to limit the production of hydro power and wind power to stabilise the grid. The function of local flexibility markets is in essence the same as for a national balancing market where customers can sell their capacity to the grid owner. However, in the CoordiNet project, customer to customer sales has been tried out on Gotland (Vattenfall, 2022). For the project in Stockholm, called sthlmflex, the first available service is up regulation, based on the current needs in the region (Svenska kraftnät, 2023e). Apart from the two projects sthlmflex and CoordiNet, there is also a pilot project in the Gothenburg area called Effekthandel Väst, which is the first establishment in Sweden without the involvement of SvK (Power Circle, 2022). While several projects are currently running, there are still a lot of things to be done until there are fully functioning local flexibility markets in Sweden (Vattenfall, 2022). So far, the local flexibility markets only exist as pilot versions (Power Circle, 2022).

4. Theoretical framework: Industrial Network Approach

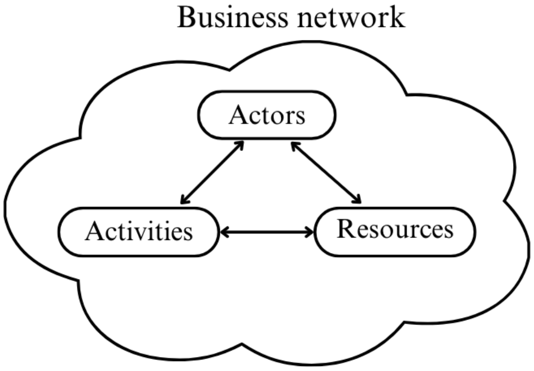
After the pre-study, it became evident that the scope of this research domain involves a complex network consisting of numerous actors and stakeholders, a diverse regulatory landscape, and varying activities and resources required to successfully implement a BESS. Furthermore, both the BESS market and balancing market is subject to a changing environment, where alterations in one aspect inevitably influence the outcomes of others. This is in line with Håkansson et al. (2009) stating that the value of one resource is determined by its combinations with other resources. This interdependency and interplay between resources, activities and actors emphasizes the need of a network perspective when evaluating the business opportunities for BESS.

The Industrial Network Approach (INA) is one such tool that is commonly used to conceptualise the process and outcomes of interaction (Håkansson et al., 2009), and is therefore chosen as the major theoretical framework for this research. INA has been used in various contexts and studies. Pagani and Pardo (2017) used the framework when analysing digitalization in a network of actors and Finke et al. (2016) studied business networks in the context of climate change. Gadde and Hulthén (2009) used the model to get the industrial network perspective on logistics outsourcing while Lind and Melander (2019) used INA to analyse the supplier interface in technological development. Thus, INA has proven effective in various studies of networks, making it a suitable lens for assessing this network of actors, activities and resources needed when evaluating the suitability of BESS at DB Schenker's distribution terminals.

Håkansson et al. (2009) explain that a way to map a business network is by applying the ARA-model. This model comprises of three dimensions including actors, activities, and resources, as seen in Figure 8. These three elements are in turn connected through activity links, resource ties and actor bonds. Each dimension alongside with their connections are explained in more detail in the subsequent sections.

Figure 8

Illustration of the components found in the Industrial Network Approach.



Note. Adapted from Håkansson et al. (2009).

4.1 The actor dimension

The actor dimension encompasses those individuals and constellations of individuals that execute activities or those who have the authority to manage various resources (Håkansson & Johanson, 1992). The same authors also describe that an actor can also be characterised by the knowledge regarding other activities, resources and actors in the network in which they operate. Håkansson et al. (2009) elaborate that the actor bonds are built upon the collaboration and mutual dependence that forms between individuals through interaction over time.

Actor bonds are highly important as they shape the capabilities and characteristics of a firm, but also the perception of the firm by other individuals in the network, and thus the possibilities for action (Snehota & Håkansson, 1995). *"Everything is possible if an actor gets the support of the network, while at the same time nothing can be done if the network goes against the actor"* (Snehota & Håkansson, 1995, p. 201). Håkansson et al. (2009) explain that actor bonds can be varying in strength, and that interaction between actors can thus vary as one is not able to forge strong actor bonds with all its counterparts. Because of this limitation, supplier selection should be done with high consideration as it affects the company's identity and ultimately, its success (Snehota & Håkansson, 1995).

The constellation between actors is not static. Rather, it changes and develops over time. Yoo et al. (2012) explain that reconfigurations of relationships are triggered by the introduction of new technology. Similarly, Lindkvist et al. (2023) express a need for the network to be dynamic in development phases. They distinguish different roles an actor can take in such a developing environment, including orchestrators, regulators, and service providers. Regulators, such as the EU, possess an important role in forming standardisation as they have an influential position. The orchestrators instead offer coordination, and the service providers develops and commercialize the services. When the technology and market mature, actors are likely to take on novel roles, where new competencies, interactions and routines may be needed (Lindkvist et al., 2023). Nyström et al. (2014) state that any change to the network will have impact on actor's roles, referred to as role temporality. Some established roles may also disappear as processes gets standardised (Lindkvist et al., 2023). While various roles often exist in a network, one actor may take on several roles simultaneously (Nyström et al., 2014). This role multiplicity can be a strategic move for firms where the set of roles can be regarded as a resource. Meanwhile, there is a risk of role conflicts if the expectations of each individual role is vague or ambiguous (Nyström et al., 2014).

Another important dimension impacting the relationship is power (Malik et al., 2018). The power that actors inflict on each other can be varying and Chicksand (2015) argue that the overall success of a partnership increases when there is a balance in power between the parties. According to Durkin and Howcroft (2003), technology can change the power dynamics of already established relationships which could either benefit or harm the relative position of an actor. One such example mentioned by them is the Internet that was a breakthrough technology providing customers with access to information, increasing their relative power. In a changing technological environment, Durkin and Howcroft (2003) also highlight the need for new training of employees to be able to cope with the new circumstances. That knowledge and technical expertise can help to increase relative power is further argued for by Malik et al. (2018).

All actors in a network have their own identity, formed by previous experiences. Depending on those experiences, actors may look through different lenses when encountering an unfamiliar concept or phenomena (Snehota & Håkansson, 1995). Anthony and Tripsas (2016) also argue that how you take on new situations and innovations as a firm is highly influenced by the organizational identity. While innovations are characterized by changes, uncertainties and new grounds, organizational identity can be well rooted and difficult to change, possibly causing conflicts between the new technology and the existing organizational identity (Anthony & Tripsas, 2016).

4.2 The resource dimension

The resource layer refers to how different resources are tied together through mutual adoptions, and these adoptions can make the resources more efficient and valuable. Håkansson et al. (2009) argue that a single resource is invaluable. Rather, the resource's value is found in its interaction with other resources. Therefore, its ability to generate economic value is also determined by its symbiosis and relations with other resources. For this reason, resources should be regarded as relations rather than isolated components, and be measured relatively (Snehota & Håkansson, 1995). Furthermore, Snehota and Håkansson (1995) argue that no actor has access to all the resources themselves, resulting in trade between companies which in turn creates business relationships.

When resources become adapted to other actors' resources, the actors get tied together which gives rise to resource ties. Snehota and Håkansson (1995) explain that as more and more resources are combined, actors develop relationships which ultimately results in higher quality resources for both parties. In these relationships, existing resources can be used in new ways and affect the company's ability to innovate (Snehota & Håkansson, 1995).

The importance of resources for a successful business have been pointed out by numerous researchers. For example, the resource-based view considers resources as the key component for determining a firm's strategy and the main source of its profitability (Grant, 1991). The resource scarcity also acts a major cornerstone in economic theory, highlighting the importance of resources (Eklund, 2013).

The resource dimension includes both tangible and intangible resources. The intangible resources include among others trust, goodwill and company image (Snehota & Håkansson, 1995). One factor affecting these resources is sustainability. Lee and Rhee (2023) has found a positive correlation between the consumers' trust and loyalty towards a brand and the firm's ability to act sustainable. Correspondingly, the brand can also be harmed if not meeting the sustainability expectations of the customers. It also affects the perceived monetary value of the offered products as there is a higher willingness to pay if the company's offering is sustainable (Bain & Company, 2023; Haller, 2022; Lera-López et al., 2013).

Another highly central resource of intangible nature is knowledge. There are different ways of learning in a network, where Snehota and Håkansson (1995) presents three of them. First, you can decide to acquire the same knowledge that the knowledge provider has, which results in high control, but can be costly and not in line with the theory of specialization. Another way is to make use of the knowledge of another actor and follow their directions. For this, you must rely more on another counterpart's ability, but the costs are drastically reduced. The third option presented by Snehota and Håkansson (1995) is gaining knowledge from joint learning with the other counterpart, where both parties become specialised in this joint matter. Building up a continuous relationship with another party enhances the actor's probability of achieving learnings (Snehota & Håkansson, 1995).

Resources also consists of various levels of control through the owning mechanism. Snehota and Håkansson (1995) reason regarding different options. Having full ownership of a resource gives a more direct and tight control, increasing your ability to utilize that resource, which is desirable. However, there are also drawbacks presented. One such is that expansion of the resource collection may be more difficult with full ownership compared to using exchanges in relationships. It is also argued that with direct control, the efforts may be spent in a certain direction, which may in the long run result in ineffective use of that resource. Instead, loose coupling could arguably be suitable in some cases. Here, Snehota and Håkansson (1995) argue that this is especially the case in unpredictable and complex environments over time.

4.3 The activity dimension

Activities are defined by Snehota and Håkansson (1995, p. 52) as *"a sequence of acts directed towards a purpose".* Through its network of connections, a company's activities are linked to a broader context, shaping what it can achieve and how they can collaborate with others. In a collaborative relationship, firms align activities and even activity structures to be better coordinated and adapted towards each other's, thus forming activity links (Håkansson et al., 2009). These links represent interdependencies between activities, shaping how tasks are executed which in turn will influence the effectiveness of those activities and thus also the revenues and costs for the firm.

The activities can be of different types, such as administrative, commercial, or technical and they can be linked sequentially as well as parallelly in the supply chain (Snehota & Håkansson, 1995). Adaptation of activities is done gradually, and the strength of the links formed varies between relationships even though novel activity links tend to come with an increased performance. One explanation for this by Snehota and Håkansson (1995) is that large adaptations in activities might involve reshuffling of tasks, possibly disrupting established routines in a firm. Furthermore, due to the complexity and interlinkages between the actors, changes in- or new activity links do not just affect the individual firms and their performance, but rather the network in its entirety (Snehota & Håkansson, 1995).

When applying and developing new technology in your business, the actors, their roles and activities are likely to change over time (Håkansson & Olsen, 2012). Completely new roles can emerge, as new activities are included within the business model (Palo & Tähtinen, 2013). This could for example include new coordination activities or organization of the infrastructure needed. Overall, Palo and Tähtinen (2013) explain that in emerging business models, the roles and responsibilities for each activity are dynamic and flexible.

5. Empirical findings

5.1 Operations at distribution terminals

A distribution terminal at DB Schenker is a large facility where goods from different regions are aggregated, sorted, and sent onwards to their destination. The daily distribution and collection at terminals start between 05:00–09:00. The distribution vehicles consist of vans and trucks with load capacities of 3.5 tons and 16–25 tons respectively. The vehicles leave the terminal successively after the starting time and most vehicles have left the terminals by 08:00. The drivers work in 9-hour shifts where they either deliver goods to their destination or collect goods for further transportation domestically or internationally. Once finished with all tasks, drivers return to the terminal between 14:00–17:00 depending on their starting time. Respondent 4 explains that most vans procured today are already electric, and that by 2030, the entire fleet will be electrified. For the 16–25 tons distribution trucks around 50–60% of the fleet will be electrified by the same date.

Apart from distribution vehicles, DB Schenker's distribution terminals also operate two types of line-haul transportation with heavy trucks. Respondent 2 describes that the first type of line-haul transports less than truck loads with weights typically over 1 ton. These vehicles perform milk runs where they collect goods from several customers, to then transport the goods directly to the destination. Thus, these trucks do not pass by distribution terminals but rather travel directly from customer to customer. The second type of line-haul transportation is that which travels between different distribution terminals. These trucks are loaded in the evening with the goods that come in from the distribution vehicles during the day. Once filled, they travel during the night to their destination to have the goods ready for distribution the next day. According to Respondent 4, electrification of these line haul trucks will occur significantly slower than for the distribution vehicles. Even though DB Schenker currently only has one of these vehicles operating as part of a pilot project, Respondent 4 highlights the future challenges with a widespread adoption of electric line haul transports:

> "*There is also the issue when all the distribution trucks need to charge, and then the linehaul vehicles arrive. Because these are only at the terminal for a short period of time, it is essential to be able to deliver fast charging to those trucks. [...] and when you look at the big terminals, they can have quite a few heavy trucks. It is not seldom that 28 of those trucks are at the terminal simultaneously waiting to get loaded with goods."* – Respondent 4

5.2 Case descriptions

From internal documentation at DB Schenker, three cases have been selected to highlight three different scenarios for future electrification potential of distribution terminals. In all cases, it is assumed that the terminals successfully implement a 100% electric distribution vehicle fleet with currently existing battery technology. Line haul trucks are not taken into consideration as large-scale electrification of these vehicles is still not possible with existing technologies. The first case depicts a dated terminal with low electrification potential where there exists a large discrepancy between available and required power during the charging window. The second case similarly highlights a lower availability of power, but to a lesser extent. Lastly, the final case was selected to showcase a modern terminal where electrification has been in mind from the beginning, and where appropriate measures have been taken to ensure that the terminal has sufficient power availability for a fully electric fleet.

In all three cases, emphasis is directed to the distribution vehicles in terms of trucks and vans with battery capacities of 330 kWh and 70 kWh respectively, with 30% of that capacity being reserved as to prolong the life expectancy. The distribution trucks are assumed to draw 1.3 kWh/km from the chargers while the vans have a consumption of 0.4 kWh/km. Furthermore, a 20% reduction in total range is taken into consideration as a worst-case situation for the winter months. The charging window for the trucks differ slightly, although it generally takes place between 15:00–07:00 where vehicles are charged according to the first in, first out principle. Some vehicles need to cover larger distances than their maximal capacity and therefore utilise roadside chargers to top-up their batteries along their route.

5.2.1 Distribution terminal A – Low electrification potential

Terminal A has 42 vehicles consisting of 7 trucks and 35 vans. All vehicles are assumed to leave the terminal at 07:00 and return in the afternoon at 17:00, creating a charging window of 14 hours. With current routes, on average the vehicles consume 4914 kWh during one day of summertime operation and 5696 kWh during the winter.

The terminal's current maximum capacity is 335 kW and on average 116 kW is used for miscellaneous operational activities. Using all remaining power to charge vehicles would result in 31% of the fleet during summer, and 38% of the fleet during winter, not being able to get fully charged during the charging window. The power tariff charged by the grid operator is 74 SEK per kW paid monthly based on the highest power level for that month.

5.2.2 Distribution terminal B – Medium electrification potential

Terminal B has 47 vehicles consisting of 7 trucks and 40 vans. All vehicles are assumed to leave the terminal at 07:00 and return in the afternoon at 15:00, creating a charging window of 16 hours. With current routes, on average the vehicles consume 5603 kWh during one day of summertime operation and 6442 kWh during the winter.

The terminal's current maximum capacity is 503 kW and on average 176 kW is used for miscellaneous operational activities. Using all remaining power to charge vehicles would result in 11% of the fleet during summer, and 17% of the fleet during winter, not being able to get fully charged during the charging window. The grid owner charges a power tariff based on the monthly highest power level, which in this case is 38 SEK per kW per month during the summer months and 58 SEK per kW per month during the winter months.

5.2.3 Distribution terminal C – High electrification potential

Terminal C has 51 vehicles consisting of 12 trucks and 39 vans. All vehicles are assumed to leave the terminal at 07:00 and return in the afternoon at 17:00, creating a charging window of 14 hours. With current routes, on average the electric vehicles would consume 6155 kWh during one day of summertime operation and 6905 kWh during the winter.

The terminal's current maximum capacity is 1072 kW and on average 343 kW is used for miscellaneous operational activities. Using all remaining power to charge vehicles would result in all vehicles being able to fully charge both during winter and summer seasons. The power tariff charged for this terminal is similarly based on the highest monthly power withdrawal, which in this case is 45 SEK per kW per month.

5.2.4 Summary of cases

An overview of the terminals' consumption and other relevant data is given below in Table 3.

Table 3

Summary of the data for the three case terminals.

	A	B	C
Number of trucks	7	7	12
Number of vans	35	40	39
Charging window	17:00–07:00	15:00–07:00	17:00–07:00
Total consumption during winter	4 914 kWh	5 603 kWh	6 155 kWh
Total consumption during summer	5 696 kWh	6 442 kWh	6 905 kWh
Maximum power output	335 kW	503 kW	1 072 kW
Idle power usage	117 kW	176 kW	343 kW
Vehicles not fully charged during summer	31%	9%	0%
Vehicles not fully charged during winter	38%	17%	0%

5.3 Practical implementation of a BESS

5.3.1 Choosing the system

When moving forward with a BESS implementation, there are numerous factors and aspects to take into consideration. Respondent 3 expresses an uncertainty of where to begin, and whom to contact for help in such a project. Respondent 6 explains that when configuring BESS for their customers, they often start with a site-visit to collect data about the facility’s consumption patterns and determine what limitations there exists physically. For example: *Does the systems have to be moveable? Can the systems be placed inside? Where could a BESS be placed and how far is that location from the grid connection?* Respondent 8 highlights that installation costs can significantly differ based on the local premises. This is strengthened by Respondent 1 who also draws attention to the considerable variations in DB Schenker’s terminal settings, advocating for the need to individually assess each terminal to understand where important equipment is located.

> *“The earliest facilities were built in the beginning of the 70’s with the latest, apart from one just being built right now, being constructed 1993. So, there is a very large span in the age of the terminals but also in technology, power electronics and all these parts.”* – Respondent 1

One common central component is the grid connection. Respondent 14 explains that if the grid connection is already maximally utilised, there will be no additional value from implementing a BESS. Likewise, the grid connection, rather than the battery itself, can be the bottleneck limiting to which extent one can participate on the balancing market. Apart from the physical constraints, Respondent 9 underscores the importance of understanding what the purpose is with the BESS implementation to choose the correct system and a proper sizing of the system. Respondent 9 explains that their BESS are modular systems that are often tailored to the specific customer needs. The chemistries used in the battery modules, but also the choice of other modules such as switchgears and transformers highly depend on the customer’s pre-existing equipment and the customers’ aim with the BESS. Auxiliary power, peak shaving and participating in the balancing market all require different characteristics from the BESS. This is strengthened also by Respondent 6 who often uses the customer usage pattern and their expected usage estimations to determine which modules a finished BESS should contain.

> *“We need to closely consider what the customer thinks about the future. These systems will live up to 15 years so it is important to consider how their business will change moving forward.”* – Respondent 6

It is not possible to use the battery system for several purposes simultaneously. Respondent 17a explains that this is because one needs to ensure availability of the capacity that is offered to the balancing market and can thus not use that power for other activities. However, Respondent 14 sees no problems in using BESS for charging vehicles some hours and acting on balancing markets on others. The important thing is then to inform the aggregator in advance and provide a schedule a couple of days ahead, so that they can plan their upcoming supply to the market.

Furthermore, BESS can be built from first-life or second-life batteries. Respondent 10 emphasizes that a second life battery solution would be significantly cheaper, but that the warranty periods would be shorter. Respondent 6 argues second life batteries are most suitable in the stationary installations of BESS, as it is not as crucial with power density compared to mobile BESS solutions or batteries in vehicles. Furthermore, the supply of second life batteries will soon see significant increases in line with the current generation of electric vehicles reaching their end of life. Respondent 6 also argues that using second-life batteries is a way of achieving lots of benefits with BESS, while having a reduced climate impact and lower investment costs. Respondent 9 on the other hand is slightly hesitant towards second-life battery solutions as they might not offer the same stability and safety as first-life solutions do today. It is argued that overall safety would be more difficult to guarantee if having batteries consisting of many different modules with different characteristics and differing levels of wear.

5.3.2 Collecting approvals

Having chosen the details of the system, the next step for actors wanting to implement BESS is to notify their local grid owner of the planned installation. The energy provider will then investigate the feasibility with such an installation. Here, it is important recognize that while one may withdraw a certain volume of electricity from the grid, it does not guarantee the ability to inject an equivalent amount back into the grid. The determination will only be made after the energy provider completes their analysis. Respondent 8 underscores the importance of communicating your plans to the grid owner as early as possible so they can plan better and be able to avoid the long lead times. Apart from that, Respondent 15 adds that grid owners employ a queuing system based on the first in, first out principle for these types of projects and by contacting the grid owners early, you will thus receive a better queue position.

Once granted permission by the grid owner, it is necessary to secure approval from the fire authority. Respondent 10 explains that knowledge regarding batteries vary from office to office, and they may not initially be sure what battery type is possible to store inside a building and what is not. Furthermore, the requirements are not standardized for all fire departments.

> *"It's a bit like the Wild West. Because the requirement specification can vary if looking at Gothenburg or Haparanda. [...] There's no overall standard set yet."*
> – Respondent 10

Typically, the fire authority evaluates the chemistry in the batteries and determines the appropriate distances to buildings and whether any further fire protection is needed. Respondent 10 also stresses the importance of having clear routes available for the fire brigade, as well as an emergency plan on how to handle contaminated water from a fire extinguishing. Respondent 6 summarizes and says that overall, it's about being smart when doing the installation, so that even a worst-case scenario can be handled with limited consequences.

> *"Sadly, there are neither any national- or EU legislation on how an installation should look like, which currently is a big problem for this immature industry."*
> – Respondent 6

As a final pre-installation step, there might be a need to apply for building permission from the local municipality. Whether this is needed typically depends on the impact on the natural- and cultural environment, national interests, and land use of the project (Energimyndigheten, 2024). Furthermore, for large BESS or if the facilities are located within an area of sensitive natural and cultural environment, consultation with the county administrative board (Länsstyrelsen) is required. Overall, the process of collecting all approvals includes several steps and might incur long lead times.

> *"It might take quite a long time from the point in time where you start the first conversation until the point in time where the system is up and running."*
> – Respondent 6

Respondent 14 specifically mentions delays as a possible risk when implementing BESS. Respondent 13 also highlights that minor delays in various parts of the implementation in the end can add up to a significant postponement of the project realization. In Respondent 13's opinion, it is often the grid owner that acts as a brake block when moving forward in projects. By law, the grid owner cannot deny a new connection to the grid, but they can claim to have limited administrative capacity at the time, causing delays. The total processing time for the approval of the grid connection can according to Respondent 10 sometimes be in the range of 10 to 30 months. Overall, Respondent 11b concludes that there are many stakeholders involved in a process like this which inevitably increases the overall lead times.

5.3.3 Installing the BESS

When the phase of collecting approvals is done, the actual installation of BESS remains. Respondent 6 says there are no laws specifying the details of how the installation should be performed. However, Respondent 11b says that RISE has a recommendation regarding this type of installation, which is followed by a lot of actors in the business. This document from RISE includes guidance on which aspects to consider, with a central focus on ensuring safety (Grönlund et al., 2023).

According to Respondent 13, the delivery of the battery systems can take 6–8 months. After delivery, the system needs to be connected to the power grid. Then, the aggregator's measuring devices must be installed. These devices monitor energy consumption in a detailed manner and use this data to make decisions based on pre-determined logic. After installing the hardware, Respondent 14 explains that they do a software integration and makes sure everything is compatible and can run smoothly. The aggregator's hardware can act as a supervisory control system in the BESS. However, Respondent 9 explains that this function could be performed by other actors as well, such as the battery provider. Supplying a smart system to control the battery is currently an attractive business opportunity for many parties.

> *"That service brings a lot of additional value. So, a lot of actors want a piece of this cake."* – Respondent 9

The next step is then to do pre-qualifications towards SvK, which according to Respondent 13 can take an additional 3 months. Respondent 6 says these qualifications are done individually per BESS installation, so if several BESS are implemented within a firm, it would still be no joint approval of these installations.

How long the total implementation time is can vary. Respondent 13 and Respondent 10 say they usually have a one-year time frame for these types of projects. Respondent 10 also says that a best-case scenario is around 6–8 months from placing an order to a finished installation. Meanwhile, he further mentions a worst-case scenario where it takes 4–5 years from the placement of an order until it is fully up and running. While this whole procedure takes time and technology may develop in parallel, Respondent 13 argues that one needs to make the decision at some point in time, since development will always be ongoing.

> *"You cannot just sit and wait, because then the time will just pass by even more."*
> – Respondent 13

5.4 The challenges and risks

5.4.1 Knowledge gap and absence of strategy

In the discussion about the future direction of electrification, one challenge presented by Respondent 4 is the lack of internal knowledge at DB Schenker. He highlights that it is a new field where there are many uncertainties about capabilities of the technology, required infrastructure and software but more importantly that there is a lack of a comprehensive picture. This is further emphasized by Respondent 8, who thinks the changing nature of energy is causing this gap for firms in general, transitioning from a commodity to becoming a strategic matter.

> *"The electricity system has gone from being something taken for granted, since it has just worked for typically 100 years, to being one of the headlines on almost every evening newscast. So, it has gone from '0 to 100' in just a couple of years. […] Until recently, it was enough to pay the electricity bill, but now a deeper knowledge is required, e.g. to understand the difference between energy and power, the meaning of hourly prices, power tariffs, etc."* – Respondent 8

Respondent 10 also points out that the knowledge gap in the industry poises a problem for them as a distributor for battery systems. He explains that they no longer accept requests for quotations from customers as the customers often lack the knowledge and thus submit requests that are insufficient or poorly done. The persons writing these specifications generally lack information about battery systems and can according to Respondent 10 not see the difference between apples and pears in this case. Meanwhile, Respondent 13 has experienced an increasing knowledge level regarding batteries and the balancing markets among their customers due to the possibilities offered.

DB Schenker has a procurement process which typically involves a category manager, but Respondent 7 observe that there is no such role applicable for new technology. He also calls attention to how the search for suppliers will differ as compared to when sourcing established products:

> "*When it comes to established items such as company cars, we have quite a good grasp of what brands are available. But a product like this [BESS]? Well, there we have no clue. We have no idea about battery suppliers. It's like asking grandma about it."* – Respondent 7.

Apart from the absence of knowledge and experience within the field, there is no specific role responsible for the overall electrification strategy in DB Schenker Sweden, which is problematic according to Respondent 4. He further expresses the need for a fact-based decision making to succeed with the strategy and to avoid feeling-based decisions. Regarding implementing a role explicitly responsible for electrification strategy, Respondent 4 argues that it better be per country or market rather than centrally managed due to the local differences and characteristics. Respondent 7 explains DB Schenker's electricity purchasing strategy but adds that it was formulated 15 years ago and could be worth reconsidering now. Finally, Respondent 4 emphasizes the need of a broad and comprehensive perspective.

> *"You need the full picture. It's not a 'BESS or not' question, but rather you need to have a holistic view."* – Respondent 4

5.4.2 Capital expenditure

Another challenge is the capital expenditure required to make the initial purchase of the BESS. Respondent 10 observes that a lot of their customers tend to focus mostly on the upfront cost, but not necessarily other factors affecting the overall operation or the total cost of ownership such as the lifespan of the battery cell.

> *"They only care about buying the solution at lowest price possible, but service, support and a demand for competence among the installers is not accounted for."*
> – Respondent 10.

From DB Schenker's perspective the economic cost calculations highly determine the willingness to invest, according to both Respondent 4 and Respondent 12. Respondent 5 mentions that the payback time should typically be within 8 years for an investment to go through. However, he also states that other factors such as environmental benefits can be included and can influence the decision making for the investment. Respondent 4 highlights the need to have appropriate depreciation rate for these kind of new technology investments as it highly affects the business case.

> *"How long should the depreciation be? For these larger upgrades [like the grid connection], the depreciation cannot be five years. Then the calculations will never work out, and DB Schenker will never be competitive in these areas. So, there is a need to review these principles of both depreciation and cost distribution."*
> – Respondent 4

Respondent 1 similarly believes the investment calculation is the most challenging aspect, because of the historically and currently high prices for the BESS. Respondent 5 continues and implies that he is not sure whether batteries are a good idea, since they are currently too expensive. When asked to estimate the cost of an average BESS, Respondent 6 believes it lays around 7 MSEK per MWh. This aligns well with other identified cases such as Effektpoolen (2022) and Johanneberg Science Park (2023) who both refer to the intervals of 6 - 9 MSEK per kWh. Other examples are Borlänge Energi (2022) who invested in a 10 MW/10 MWH system for the cost of 5 MSEK per MWh in 2022 or AFRY (2022) who estimated the investment of BESS for Komatsu in 2022 to amount to around 6.7 MSEK per MWh. A lower number is presented by Power Circle who estimate a cost of around 2.2–6.5 MSEK per installed MWh. For the future, Respondent 16 believes the upfront price of batteries will decrease significantly which may help the business case. Furthermore, Respondent 16 argues that stationary batteries in particular will see radical price decreases to stay competitive with the quickly evolving electric vehicle (EV) batteries.

5.4.3 Economical uncertainty

One risk identified by both Respondent 8 and Respondent 13 is that one might rely on a certain scenario about the future in their calculations. This includes making assumptions of the future balancing markets to determine payback time. But according to Respondent 8 and Respondent 13 it is highly uncertain what the future of this market holds. This is also shown by Respondent 9, who prefers if the customer makes the business case by themselves due to the difficulty in predicting future revenue streams, and because they do not want to make empty promises about the future. Respondent 13 believes we will soon see the price drop but emphasizes that it will continue to be a well-functioning market the coming years with a compensation level that is still good. Respondent 15 foresees that the balancing market will be saturated soon, as a large Swedish actor is predicted to offer immense volumes of energy in the time to come. Respondent 17a continues and says they are far from alone in exploring and offering these types of flexibility resources, and that this causes them to also believe in decreasing returns from this market in the future.

One way of anticipating what the future holds is by looking at Great Britain, as both Respondent 8 and Respondent 15 argue that their balancing market is more developed than the Swedish one. Respondent 8 sees no reason why Sweden would not follow a similar pattern, and therefore argue that lessons could be taught from Great Britain. Many respondents think it is difficult to be sure about the future of the balancing markets.

> *"Only time will tell. It is incredibly difficult to predict. Right now, there is a kind of bustle. There is a kind of gold rush."* – Respondent 9

Even though the future holds uncertainties, several respondents agree that it is a very lucrative business opportunity currently. Respondent 8 believes the future of the balancing market's income opportunities lays in the foundations of demand and supply. He explains that traditionally, we have adjusted electricity production to the need, and now it's the opposite: we need to adjust consumption to the production and that is where flexibility comes into play. The demand of flexibility on the electricity market will increase linearly with the amount of intermittent energy production, such as wind and solar power. What there is to earn on the battery solutions is therefore directly dependent on the balance between demand and supply of flexibility. Respondent 16 also focuses on the introduction of intermittent energy when speculating about the future.

> *"The balancing market is here to stay. We introduce more unsteady consumption from EV charging, while also introducing more unsteady production from solar and wind power. However, the compensation levels will surely go down pretty far as more and more actors join to offer these services."* – Respondent 16

How this demand and supply balance will look in the future is unsure, and Respondent 8 draws parallels to another recent gold rush in Sweden that only lasted for a couple of years and resulted in an exploding supply:

> *"Are batteries the new padel courts?"* – Respondent 8

The reference to padel effects is also done by Respondent 13 who speculates whether there is an ongoing battery boom and says a lot of actors are wondering how the compensation levels on the balancing markets will develop. Respondent 6 is sure that the need for flexibility and frequency regulation will rise as more solar and wind power is built. But he further emphasizes the changing nature of the balancing market in Sweden being a source of uncertainty. For example, FCR-D down has been the most lucrative business lately, and that service did not even exist on the market three years ago. Since then, the FCR-D down has not only been established, but it has already changed its price mechanism. Furthermore, Respondent 6 also adds the fact that there will be new rules in place during 2024 regarding who can offer balancing services which might have impact on the market characteristics.

5.4.4 Choice of partners

Inappropriate choice of suppliers is brought up by Respondent 10 as a risk. He explains that a lot of actors in the battery market have traditionally dealt with solar panel solutions, which are much less complex than BESS. This poses a risk of not being able to fully deliver what is promised from the supplier's side. Respondent 13 says it might be smart to go with suppliers that have conducted comparable projects in the past to know that their systems can handle a similar use case of the batteries. Respondent 6 predicts that the battery market will be consolidated soon, and that a lot of today's actors will probably not exist in five years from now. For that reason, choosing smaller actors can entail a larger risk compared to when going with a larger and more stable supplier. On the contrary, Respondent 13 reasons that the increasing number of batteries will in turn result in more actors on the market than before. To cope with and evaluate the uncertainties, Respondent 7 explains that DB Schenker usually assess the risk based on the supplier itself. For instance, this includes looking at the supplier's financial situation but also checking that they are not blacklisted in certain registries. Also, the number of suppliers affects the risk.

> *"It's a high cost and quite complex product [BESS], so then we want as few suppliers as possible. But it also poses a risk having too few suppliers. And it's also difficult to get a good price then."* – Respondent 7

On the same topic, Respondent 10 illustrates a scenario where poorly performing balancing markets might cause aggregators to go bankrupt. Respondent 14 describes that there are two aggregating roles, including the technical aggregation and the market aggregation, and both functions are needed for a firm to act on the balancing market. A bankruptcy of any of them could lead to some budget-oriented battery systems, whose EMS is provided by aggregators, being left without control systems. Respondent 13 observes that the effects of such a scenario could be limited by owning the controlling hardware, and thus having a functioning battery whose operation can be taken over by a new aggregating company.

5.4.5 Operational Safety

A recurring theme during the interviews has been safety aspects of BESS. Respondent 1 mentions that they probably do not want to have the batteries inside of a property because of the risk of fire. On the contrary, Respondent 6 argues that these kinds of logistics actors already have electric vehicles docked by the entrance to buildings and that they thereby already have accepted that kind of risk. Respondent 2 also highlights the risk of fire when handling battery solutions and question whether charging in carports is appropriate, or if that should be done by the fence, furthest away from the property. Respondent 1 says a risk analysis of placing batteries inside must be done if that option comes to the table, and he further elaborate on potential benefits of placing the battery inside the buildings. Those benefits include keeping the batteries within optimal operating temperature to ensure that no energy from the battery gets used to achieve the right temperature for example through heating. Respondent 6 and Respondent 13 also mention the importance of having clear routes available for the fire brigade, as well as an emergency plan on how to handle contaminated water from a fire extinguishing.

> *"What do we do if a fire breaks out? What are the consequences? There are lots of risks you need to be aware of and consider."* – Respondent 13

Beside fire aspects, insurance is also a relevant regard to take into consideration when placing batteries indoors. Respondent 8 emphasizes the importance of contacting your insurance provider as they will have opinions about the implementation. Respondent 11b further highlights the role of insurance companies and says that they can have a lot of requirements restricting the installation. Respondent 17b explains that if one does not have the insurance companies on board with the investment, it will affect the company's risk premium, which in turn impacts the whole business case. Therefore, the insurance providers are a very important stakeholder in the business network. One challenge here, brought up by Respondent 17b, is the lack of a consolidated viewpoint between the insurance companies, resulting in high variations in the evaluation from actor to actor in these types of implementations. The fact that this type of technology is quite novel adds complexity and may also in some cases be problematic since insurance companies then tends to take a conservative approach.

> *"We were not allowed to place the battery indoors, but then there were 12 buses in there with 430 kWh, does the requirements not apply to them? No because those batteries run on wheels, but when doing a permanent installation there were tougher obligations than for a bus that might even be damaged from accidents. That is quite absurd."* – Respondent 11b

Cybersecurity was another safety consideration brought up by Respondent 10 who elaborates that both the supplier and the battery manufacturer might have access to the management of the battery for service reasons. Therefore, Respondent 10 underscores the importance of choosing a supplier wisely and being aware of potential security issues if providing insights and access to the wrong partner. On the same matter, Respondent 16 comments that building a dependency on batteries for the national electricity system could thus pose a weak spot for cyber-attacks on critical Swedish infrastructure.

5.4.6 Not having BESS

Apart from risks with having BESS, risks with *not* having BESS have also been discussed. Respondent 10 highlights that infrastructure critical actors should invest in BESS as reserve power because not having backup energy in times of a crisis will cause substantial impacts on their operations. He further underscores that crises do not necessarily have to be geo-political but could also arise from the grid being overloaded and creating blackouts. Respondent 7 also emphasizes the risk of simply standing without electricity in times of need. Furthermore, Respondent 6 believes the ability to have some local energy backup will be valued a lot higher soon compared to today.

> *"The day anything happens in the society, it will be more clear what backup power is worth, and that will favour BESS."* – Respondent 6

5.5 Alternative solutions

It will become challenging to charge all trucks simultaneously according to Respondent 8, who also says that the Swedish electricity grid is on its way to become partially strained. But implementing BESS is not the only alternative available on the market to battle these types of upcoming challenges. Respondent 5 mentions a trade-off between expanding the current grid connection and to purchase batteries. Improving the infrastructure would increase the capacity, whilst batteries could potentially increase the overall output without requiring extensive modifications of existing infrastructure. Regarding the option of upgrading your grid connection, Respondent 8 explains that there is a connection obligation for the grid owner, meaning that you will not be denied a larger connection. However, getting an upgrade to one's grid connection can take a long time and can be very costly according to Respondent 8.

Another technology mentioned is vehicle to grid (V2G), which is especially relevant for DB Schenker considering the vast number of EVs they possess. Respondent 8 has noted that while this technology is widely discussed as a method of supporting the grid, almost no vehicles can perform these activities since they are constructed for charging in one direction, not bi-directionally back to the grid. He further believes that this will change around 2025–2026 and that regulations will probably come into place and refers to its high potential:

> *"Passenger cars are normally parked approximately 90 % of the time, which would mean that there will be a significant amount of battery kilowatt-hours available for e.g. supporting the grid, provided that the cars are connected."* – Respondent 8

Respondent 7 also sees that V2G solutions have an interesting potential for an actor like DB Schenker, even if the technology is a couple of years away. However, Respondent 8 also highlights today's limitations with V2G due to the immature laws and regulations:

> *"Present electricity legislation doesn't take any battery storages moving on wheels into account. This means that charging and discharging at different locations need to be included, for e.g. taxation reasons."* – Respondent 8.

On the contrary, several respondents say the regulatory system has already accepted having the vehicles standing indoors, and thus they do not expect any major regulatory changes. Instead, Respondent 16 identifies two other aspects that constitutes the bottleneck. First, the car companies' structure of how to handle warranty matters and insurance is not ready for an introduction of V2G systems. Second, there is a lack of standards among the car batteries to be able to communicate with the controllers of the charging infrastructure. However, Respondent 16's company believes this is set to change soon causing that market to open. Because of this, they have developed a bidirectional EV charging infrastructure. According to Respondent 16, most actors in the network of V2G are already prepared to embrace this technology and they are just waiting for the vehicle manufacturers to allow this kind of usage for their vehicles.

Also, hydrogen power solutions are mentioned by Respondent 8 and Respondent 10. However, Respondent 10 reasons that hydrogen will have a hard time competing against BESS, as quick availability to power is difficult to reach along with the fact that it is quite energy demanding to produce hydrogen. Respondent 15 believes these technologies can coexist as they do not directly compete in the same field and areas of application. Finally, energy storage options such as salt storage, thermal storage and flywheel energy storage are mentioned by Respondent 6. He does not see this as a threat to BESS. Instead, he believes there is room for all these techniques to co-exist thanks to the market growth. Similarly, Respondent 10 does not foresee that the batteries will be outcompeted in the future.

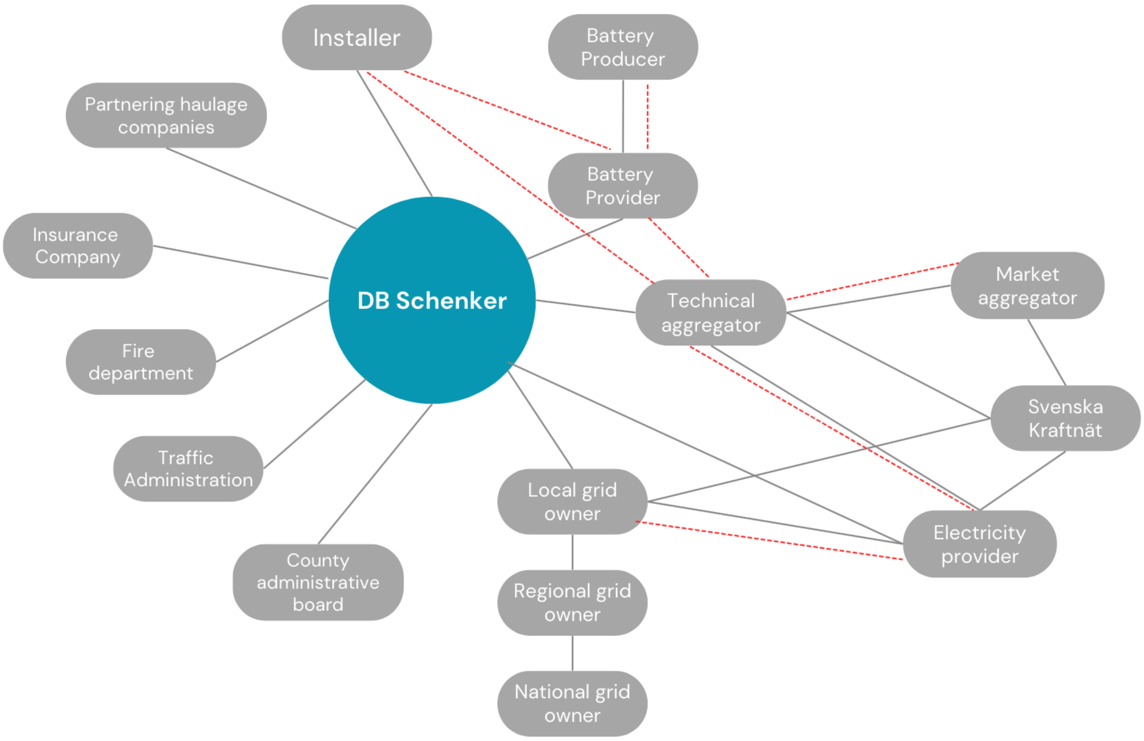
6. Analysis and discussion

6.1 Implementing BESS – The actor dimension

The empirical findings indicate that an implementation of BESS involves numerous actors, who are connected to each other in a network as illustrated in Figure 9. Each actor can take on different roles, where one actor may sometimes span over multiple of the traditional roles, which is in line with previous research from Nyström et al. (2014) and Lindkvist et al. (2023). This is seen for instance where larger grid owners also offer the services of an aggregator and/or electricity provider. This is one aspect to consider when choosing whom to partner with when implementing BESS. Furthermore, the larger actors are usually more established, have a proven record of quality and will likely remain in the future, with the possible drawback of having a higher cost or lacking innovative functions. As mentioned, they may also cover more roles in their offering, making the network consisting of fewer actors and possibly reducing complexity and coordination efforts needed. The smaller and more novel actors can meanwhile act more agile and offer more innovative or tailored solutions, or a more competitive price. However, this could impose a higher risk as they may not have the same stability and track record as a larger actor on the market. Partnering with several smaller actors could also result in a network with an overall higher number of actors involved, calling for increased coordination. This coordination must not necessarily be performed by the customer itself, in this case DB Schenker, but could also be done by other actors in the network. Furthermore, the empirical findings show that many actors already have established relationships and actor bonds with actors in other roles, thus being in an advantageous position in the network. By partnering with those actors, DB Schenker can reduce the complexity of having one actor bond for each role in the network and thus be able to concentrate efforts to maintain fewer, but stronger actor bonds. Overall, as Snehota and Håkansson (1995) also points out, the supplier selection is a highly important decision as it affects not only the capabilities and characteristics of the DB Schenker but also their overarching success.

Figure 9

Snapshot of current actor bonds in the network.



Note: Grey lines represent communication. Red dotted lines means that the role could be taken by one and the same actor in practice. Both the Swedish Government and EU are excluded from this visualization as any regulation from them would affect all actors. Including them would decrease the visibility of the mapping.

Some of the roles are not yet obvious and standardised. This is especially true for the role of managing the logic of the battery operations, where respondents with different positions all said they wanted to be the responsible actor for this feature. This is in line with Palo and Tähtinen (2013) who argue roles are dynamic and constantly changing and may especially tend to change in immature industries. Similarly to the findings of Lindkvist et al. (2023) and Palo and Tähtinen (2013), it is evident from the empirical findings that new roles may emerge as the BESS field has a changing nature. As empirical data highlights the initial investment as a limiting factor in the business case, leasing actors could potentially get a more prominent role in the future network of BESS actors.

The actors within the business network exert different levels of power on each other. For example, when choosing the hardware for the BESS application, DB Schenker can choose from several actors who all provide these systems, meaning that the distributor's level of power is relatively low. On the other hand, insurance companies are an example of an actor with a high level of power. Even though there are multiple insurance companies available, DB Schenker already has ongoing relationships and contracts with specific insurance providers, restricting freedom in selecting among available options. Empirical evidence showcases the impact this type of actor can have on the whole BESS investment, as they can put a risk premium high enough to obstruct the business case or just simply deny installations. Because insurance companies can control the possibilities for action, they are a highly important actor in this network whose support is crucial for moving forward with an implementation. By involving these types of actors early on and interacting over time, DB Schenker can build strong ties to them and by doing so maximizing the potential of successfully implementing BESS at their terminals. However, the power balance is not static and may shift with changes to the network such as introduction of regulations or technological advancements. Just as Durkin and Howcroft (2003) illustrated with the example of the Internet breakthrough, shifts in the network can reshape power dynamics. Therefore, understanding, and prioritizing relationships becomes important to maximize the success in the network.

The ARA model also emphasizes that one's identity is based on one's previous experiences, affecting how they act in the future (Snehota & Håkansson, 1995). DB Schenker is a large and traditional company, with several established relationships with companies in the business network. This could then affect what suppliers and partnerships they choose to form. For instance, charging infrastructure is already installed, and this experience could possibly impact a decision for BESS. If being content with the charging infrastructure solution, it could be beneficial to evaluate an extension of that existing relationship to also include BESS from the same supplier. DB Schenker also acts in a market characterized by low margins, which could affect their willingness to invest and their view on risks, including the risk of investing in BESS.

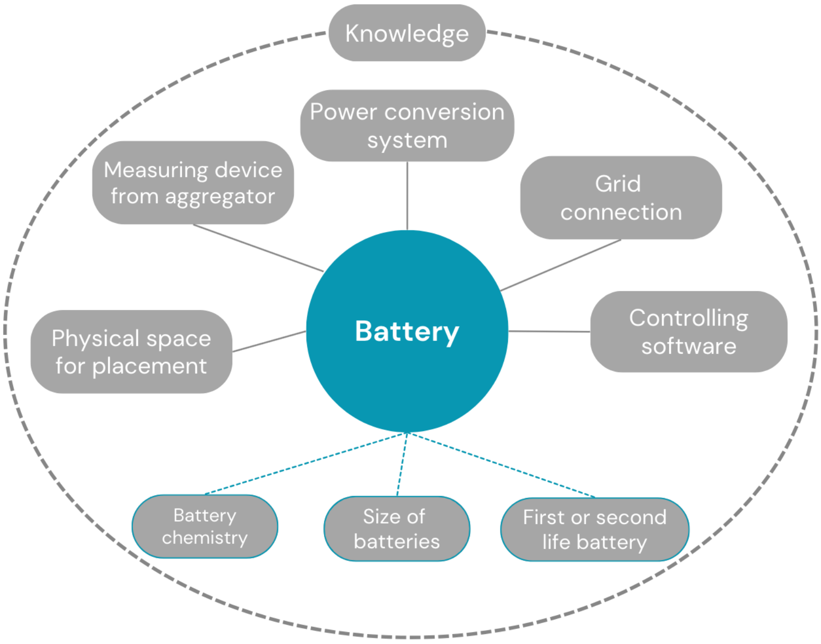
This research has focused solely on DB Schenker's own haulage company and their vehicles. However, DB Schenker has lots of partnering haulage companies, and when deciding upon investing in BESS and how it should be done, their role must be considered. If choosing to invite them to charge their vehicles at DB Schenker's terminals, a completely new picture would form. With the increased demands that would arise, significant investments into electricity infrastructure would be required. This would expand DB Schenker's role from being a purely logistics provider to also being an infrastructure provider. By having such extensive charging capabilities, it would also open the possibility of offering public charging as a new line of service. Similarly to the findings of Lindkvist et al. (2023), it can be seen that as the EV market matures, DB Schenker can possibly embrace a novel role. This is just one example of how the network might change and how introduction of new technology such as BESS might create reconfiguration of established constellations between actors in line with findings from Yoo et al. (2012).

6.2 Implementing BESS – The resource dimension

The various resources and their ties in the business network that have been identified when implementing BESS can be seen in Figure 10. When focusing on the battery itself, empirical findings highlight an importance of finding a suitable size of the BESS. Oversizing the BESS could lead to unnecessary expenses, potentially undermining the investment viability. Conversely, if under sizing, the benefits will be limited by the capacity of the battery and may not satisfy the increasing needs of the future. Some solutions offered on the market do however appear to be relatively modular, opening the possibility of expanding an existing BESS down the line. Additionally, empirical findings reveal that the current grid connection can limit the BESS applications and sizing options in some respects. For example, dimensioning the BESS for a capacity over the current power limit of the grid connection yields no additional advantages when participating on the balancing market as the maximum bids will be capped by the grid connection. However, a higher peak capacity of the battery could for instance be beneficial in the future if more fast-charging infrastructure were to be installed on the terminals. Thus, it is evident that resources are highly interconnected and impact each other in different ways, requiring actors to look beyond the immediate resource ties but also to consider the long-term implications of a decision. This aligns well with Respondent 4 who pointed out the importance of having a holistic view when it comes to the electrification plans in general.

Figure 10

Illustration of resources present in a BESS implementation.



Note: Blue dotted lines represent configurations of the battery itself.

Another aspect to consider when discussing the battery hardware is the choice of battery chemistry and whether to go for a first-life battery or a second-life battery solution. As suggested by the empirical findings, focusing solely on upfront costs could be disadvantageous and lead to a higher total cost when taking into the account the lifespan of the BESS. Thus, while certain chemistries or second-life batteries may be cheaper initially, it can still be beneficial to evaluate other alternatives with higher upfront costs. The reduced climate impact and the safety aspect with second-life batteries are also aspects to consider when deciding. In this study, the respondents advocating for either side may have had personal gain in their responses which is why there will not be a specific recommendation. Rather, it is shown that there are different options to choose from with all options providing different benefits and drawbacks.

Another resource in the industrial network approach is knowledge, of which the absence has been identified in the empirical findings as a major challenge to moving forward with BESS. As the field of BESS is a new area which has previously not been important to most firms, some actors have fallen behind in when it comes to knowledge. Subsequently, as knowledge is a source of power according to Malik et al. (2018), those actors have a lower relative power compared to other actors already established. By improving knowledge regarding BESS, actors can improve their relative power position which according to Chicksand (2015) improves the chances of successful collaboration. This can be done for example by understanding what technical requirements and preferences the firm has, what options are available on the market and what the future outlook is. Empirical findings also show that the industry of BESS is still immature, where both roles, technology and regulations are expected to develop further in the near future. This further raises the need for DB Schenker to stay á jour with the market and technology advancements, in order to make informed decisions and investments as advocated by Respondent 4 in the empirical findings.

As emphasized in the INA theory, knowledge can be gathered in different ways (Snehota & Håkansson, 1995). There are for example learning opportunities when collaborating with other actors in the network, meaning that all knowledge must not be present within DB Schenker but rather within the network. Looking outside the network is another possibility to gain knowledge. From the empirical data, Great Britain emerges as a more developed market and can therefore offer insights and experiences for learning. By collaborating with the right actors, DB Schenker can access and make use of knowledge that others possess. This could also be more economically viable, as knowledge is a resource that takes time to build up and to regularly maintain. Instead, DB Schenker could focus on increasing the knowledge level on certain specifically important areas as it comes with a higher level of control according to Snehota and Håkansson (1995). Empirical data indicates that a common way to realise projects like BESS implementations is by buying a pre-study or a consultancy project to carry out the various implementation steps. By purchasing such a service, the knowledge barrier can be overcome although with the drawback of increased expenditure. However, a certain level of general knowledge would still be beneficial to interpret the outcomes and being able to make informed decisions thereafter. DB Schenker may possess knowledge from previous electrification projects which could also be applicable to a BESS project. This way of using existing resources in new ways and contexts has been proven to increase a firm’s ability to innovate according to Snehota and Håkansson (1995).

Apart from the direct costs and savings from a BESS implementation, there are also indirect consequences for resources which are more difficult to quantify. Without sufficient power to charge vehicles, the electrification of the vehicle fleet will fail, leading DB Schenker to miss their climate goals and potentially harm their business. For example, consumers’ trust and loyalty towards the brand of DB Schenker can decrease, in line with the findings of Lee and Rhee (2023), which in the INA theory is part of a firm’s intangible resources. By not meeting climate expectations by customers, the perceived value of DB Schenker’s services might also decrease due to the willingness to pay being higher when a product or service is seen as sustainable (Bain & Company, 2023; Haller, 2022; Lera-López et al., 2013). Thus, ensuring adequate power supply for vehicle electrification is not merely a matter of meeting environmental targets but is crucial to keeping DB Schenker's market position and financial performance.

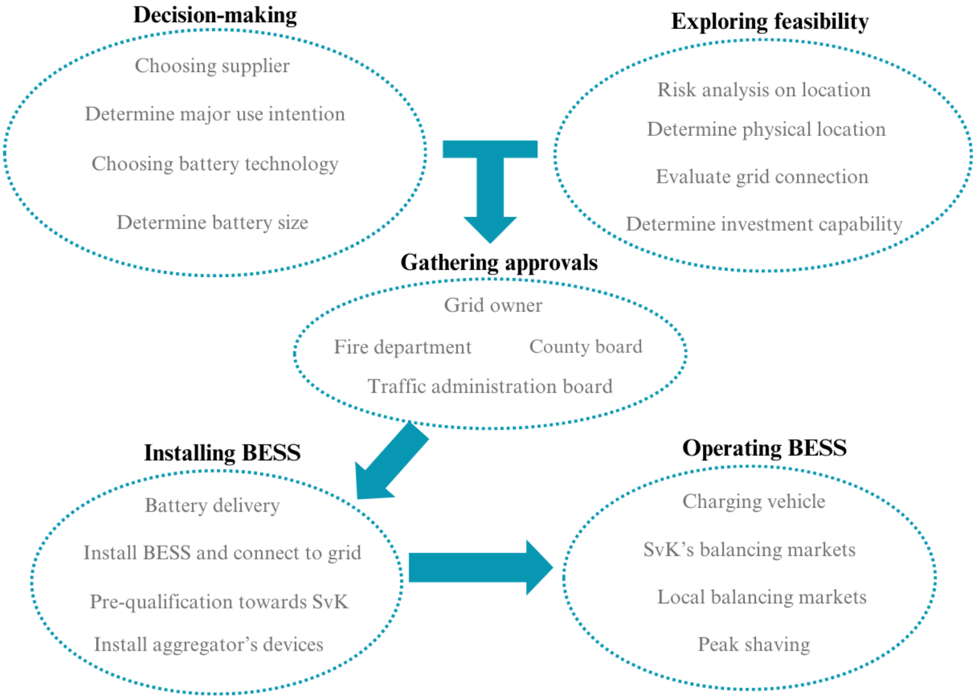
Not being able to use the electrical vehicles to their full potential would also be costly in terms of lost business. As the range and usage of vehicles is directly derived from the ability to charge when needed, insufficient power will highly lower the utilisation rate of this central resource. To still deliver in a scenario where vehicles cannot fully charge at the terminal before their operations, DB Schenker might be forced to continue using their non-electric vehicles or charge their electrical fleet at a higher cost elsewhere. Continuing using combustion engine vehicles may also become more expensive in the future with the expansion of emission rights, further highlighting the importance of succeeding in the electrification journey.

6.3 Implementing BESS – The activity dimension

The overview of a BESS implementation given in Figure 11 depicts the wide span of activities needed. Having this vast number of activities rises the overall complexity and may cause a long implementation time. As presented in the INA theory by Snehota and Håkansson (1995), activities can be performed sequentially or parallelly, which is also the case here. The empirical findings show that some activity clusters typically happen in a particular sequence, while others can be performed simultaneously. The activities within each phase can for most cases be done in parallel. Being able to perform activities in parallel enables firms to shorten the lead time of a BESS installation. As the uncertainty grows further into the future, a reduced lead time can aid DB Schenker better predict the outcome of their BESS investment.

Figure 11

Simplified overview of major activities in the implementation of BESS.



In the decision-making phase, all activities are interconnected, and each choice affects the remaining ones. For example, determining the major use intention highly impacts what battery technology and what size of BESS is suitable. This in turn narrows down the available options for the choice of supplier. It can be seen that the major use intention of the BESS dictates most other activities in the decision-making phase. Thus, it is beneficial to commence a BESS implementation by identifying and prioritizing the primary use intention.

During the phase of exploring feasibility, the activities are more independent and separated from each other. These activities may even be performed by different actors, internal or external, enabling a utilization of different competencies. The evaluation of grid connection can require a more technical viewpoint while investment capability may require involvement of upper management and stakeholders. This activity phase can be carried out in parallel with the decision-making activities, as none of them are dependent on output from the other. The remaining clusters are typically performed more sequentially, as the completeness of one phase may be required to commence the succeeding activities.

The gathering of approvals from different actors can also be performed simultaneously, and the activity links are not as strong as seen in the decision-making phase. The likelihood of receiving an approval quickly is greater when being aware of each actor's requirements, as well as providing sufficient and relevant information in the application. All approvals have this in common, but what is requested varies. The fire department is interested in emergency plans and safety measures such as distance to buildings and handling of contaminated water, while the grid owner needs to make sure that the grid can handle an additional resource and thus want information on technical specifications of the planned BESS. Thus, having the knowledge to supply the right information to each actor can help to speed up the process and avoid delays.

For the installation of BESS, cooperating with external actors appear common. After having received the BESS, connecting the equipment to the grid is usually done by a third part. However, empirical findings point towards a lack in standardised installation procedures, and thus the exact performance in this phase can vary today. Similarly, the measuring devices required by the aggregators are seldom installed by the customer themselves. Rather, the aggregators help with the installation and support during the pre-qualification towards SvK which is needed to participate in the balancing market. It is evident that several actors are required and that they must collaborate to synchronize installation efforts and minimize disruptions during deployment.

When it comes to the activities performed when the BESS is operational, these are highly adapted towards SvK's balancing market. However, in the future other actor bonds could be created, and new activity links formed, for instance by using BESS for local flexibility markets. Allocating the BESS resource to a certain activity affects other activities. An example is participating on the balancing markets, which has an impact on the ability to charge the vehicles in the meantime as capacity must be reserved in accordance with cleared bids. In the future, the activities may change, and other usages of BESS can become increasingly relevant. Apart from acting on balancing markets, the peak demand management method of peak shaving can be performed. While peak shaving to this day has not been the most economically beneficial use case of BESS, it could potentially become a larger business in the future. This is partly due to an expected decrease in the returns from the balancing markets as seen in the empirical data. It also stems from the fact that power tariffs are becoming increasingly adapted all over Sweden and will according to the empirical findings consist of a larger portion of the total energy bill moving forward. These two factors will both incentivise the use of BESS to decrease peak power demands.

The activities may also be impacted by new regulations, nationally or on EU level, which according to the empirical data has been absent this far but is expected to come soon. According to Lindkvist et al. (2023) the regulatory role can help forming standards. Relating to a BESS implementation, legal instances could act as regulators to develop standardized activity patterns. For instance, standardized acceptance criteria for the fire prevention authorities could emerge as the current approvals appear to differ all over Sweden. Similarly, empirical findings point towards a lack of standards in installation methods where current activities rely merely on a recommendation from RISE. In the future, the regulatory role could potentially also be possessed by the insurance companies. They have the power to form standards exceeding the regulatory minimum by placing further requirements on what activities should be performed to receive insurance for BESS. By adhering to clear standards, rather than working case-by-case, actors could more easily adapt their activities towards each other, forming strong activity links. These activity links could improve performance in line with INA theory, for example through best practices emerging for installing BESS which would reduce installation time and ultimately reduce costs.

6.4 The business case

The quantitative model that lays the foundation for the business case of BESS at the different terminals is based on internal documentation from DB Schenker and historical prices for balancing services from Svenska kraftnät (2024f). To calculate the potential income from BESS, the model solely utilises SvK’s balancing services FCR-D up- and downregulation as they are the most used and most lucrative alternatives according to empirical findings. On the cost side, most identified estimations lay around 6–9 MSEK per installed MWh which will be used to estimate the span of payback time in each of the cases.

While the calculations offer a starting point for estimating the potential profits from BESS deployed at distribution terminals, they are of a simple character and have several assumptions and limitations. Therefore, it should only be seen as a broad guidance on the possibilities of using BESS to generate an income. For example, it is assumed that all available capacity can be cleared on the market and therefore that there is always a sufficient demand for FCR-D. Furthermore, it is assumed that a grid connection has equal power limits in both directions of flow. Additionally, no fees or surcharges are considered that may be charged by aggregators or any other actors necessary to participate in the flexibility markets. The remuneration for balancing services used is taken as an average over the last 5 years for FCR-D upregulation and the last 2 years for FCR-D downregulation.

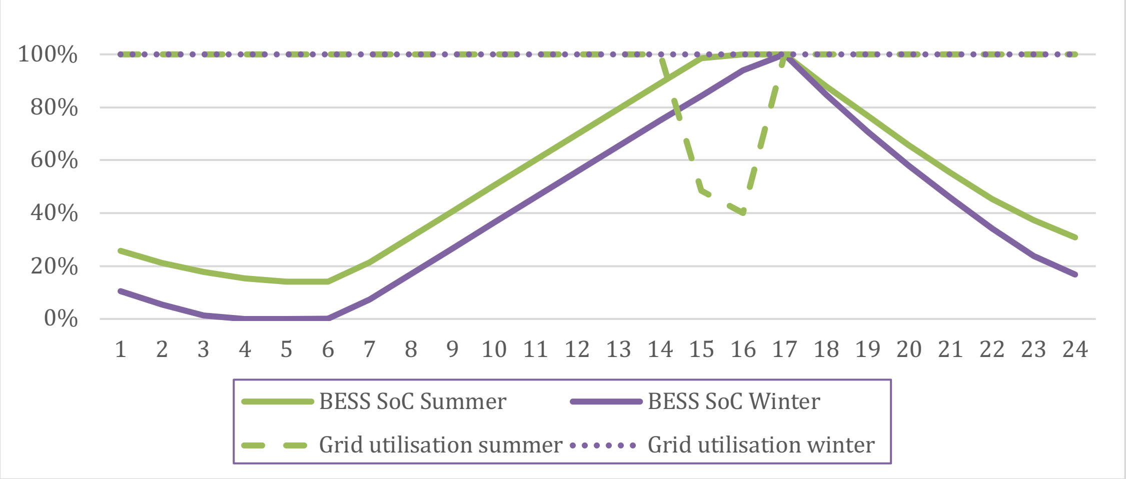
As highlighted by the empirical findings, one of the most important first steps are to determine the use case of the system. In this model, the dimensioning of the BESS is done according to the minimum size required to achieve full charging of the entire vehicle fleet during the charging window. The chosen way of dimensioning the BESS does therefore not allow for any peak shaving and only limited possibilities for participating on the balancing market. However, currently peak shaving is not an attractive alternative due to only yielding between 38–74 SEK/kW monthly, while FCR-D up- and downregulation currently had a monthly remuneration of 315 SEK/kW and 578 SEK/kW respectively during 2023 (Svenska kraftnät, 2024f).

6.4.1 Distribution terminal A – Low electrification potential

Distribution Terminal A has the weakest grid connection among the three cases. Out of an average maximum power output of 335 kW, 116 kW is allocated for miscellaneous activities, leaving 219 kW available for vehicle charging. Over a 14-hour charging window, a total of 3066 kWh of electricity is available, while the required amounts are 4914 kWh and 5696 kWh during summer and winter, respectively. This results in a discrepancy of 1881 kWh and 2663 kWh during the two seasons. With 2190 kWh of energy available outside the charging window, implementing a BESS equal to the that could enable all vehicles to fully charge during the summer. However, for winter operations, there would still be a shortfall of 473 kWh. In this case, the BESS would not be able to compensate for the shortfall due to grid limitations, even when fully utilising the grid at all times. However, implementing the BESS would increase the percentage of vehicles able to fully charge from 62% to 90%, with the remaining vehicles achieving a higher state of charge (SoC) compared to the baseline. A simulation of the SoC of the BESS as described above can be seen in Figure 12.

Figure 12

Simulation of BESS SoC and grid utilisation throughout the day for terminal A.



Note: The simulation is based on internal documentation of energy consumption combined with actual usage patterns of vehicles at DB Schenker.

From Figure 12 it can also be seen that FCR-D upregulation is possible in the summer throughout the day as the BESS always has a SoC higher than zero. However, with only 309 kWh of excess grid capacity throughout the day, repeated activation by SvK would obstruct fully charging the BESS, potentially depriving some vehicles of sufficient electricity. Given that none of the cleared bids require activation, remuneration for FCR-D upregulation could reach 620 000 SEK for the summer season. For the winter operations, no bids for FCR-D upregulation could be placed as the grid connection is at maximum usage throughout all hours of the day, meaning that any activation of the resource for FCR-D upregulation would sacrifice the ability to charge the fleet. Consequently, the ability to generate revenue from the balancing market would be equal to zero during winter. The ability to participate in FCR-D downregulation is similarly limited as the grid connection is utilized to 100% for the most part of the day for both seasons. The result is that FCR-D downregulation can only yield 62 000 SEK of revenue during the summer, and nothing during winter. Relating the income from the BESS with its estimated costs, the payback time would range from 19 to 29 years depending on actual installation costs.

It is evident that the grid connection severely restricts this terminal, and while BESS could alleviate some charging issues, enhancing the grid connection would be beneficial, particularly in winter. However, with an upgraded grid connection comes not only the initial capital expenditure required for the installation but also increases in the power tariffs that comes with the higher peak power output. Even though these figures are relatively low at the time of writing this report, as empirical data suggests, they are likely to increase in the future and will therefore have a greater impact on the business case of such an upgrade.

If implemented today, the BESS could solely participate in the balancing market as the fleet would not require charging capacity. Optimizing state of charge (SoC) to 50% of the total capacity would enable simultaneous bidding for both FCR-D upregulation and downregulation. Given the grid limitations, an average bid of 219 kW for FCR-D downregulation and 335 kW for upregulation over 24 hours could yield remuneration of 1 100 000 SEK and 1 200 000 SEK, respectively. This approach would reduce the payback time to between 7–10 years for the BESS. Thus, investing in a BESS today could mean that most of the investment would be paid off by the time DB Schenker's fleet comes to a point where the available grid connection won’t be powerful enough to supply sufficient charge.

6.4.2 Distribution terminal B – Medium electrification potential

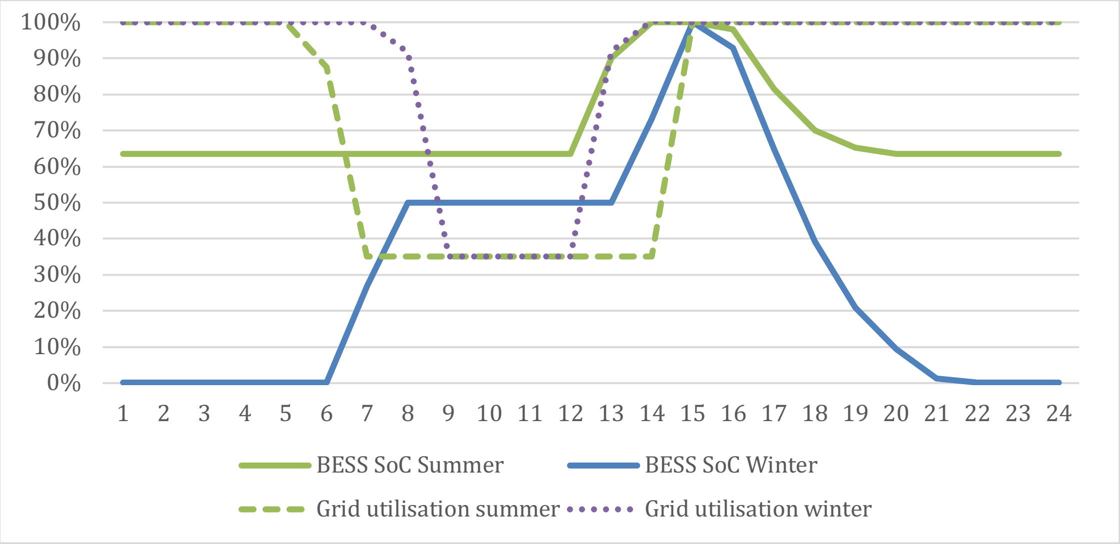
Terminal B’s grid connection enables a maximum power output of 502 kW, and the terminal has an average idle consumption of 176 kW. This leaves 326 kW available for charging vehicles, meaning that on average 5216 kWh is available during the charging period and 7824 kWh during the entire day. With terminal B’s vehicles and consumption characteristics, a fully electrified fleet would require a total of 5603 kWh of electricity during summer and 6442 kWh during winter. This means that there exists a discrepancy of 387 kWh of electricity during charging window in the summer and 1226 kWh during the winter to fully charge the entire fleet. In practice, this results in 5 vehicles not achieving full charge during summer operation and 8 vehicles during winter. As the total power available throughout the day is greater than the total consumed electricity, a BESS is therefore a good alternative to solve the discrepancy in power during the charging window. By using the BESS solely to charge those vehicles of the fleet that otherwise does not manage to fully charge, the sizing of the battery pack would have to equate the discrepancy in power, in other words 1226 kWh. However, this approach would rely on software support to control which chargers receive additional capacity. Without such control, the result would be that those vehicles that start charging first would get finished even faster, while the later vehicles would continue to have difficulties in achieving a full charge during the charging window. This points again to one resource receiving its value through the combination with other resources, as advocated by Håkansson et al. (2009).

From Figure 13, it is seen that bids for FCR-D upregulation can be placed from around 06:00–15:00 during winter with FCR-D downregulation being possible 2 hours later when the battery has been charged to 50%. The revenue that can be expected from the flexibility market during the winter months is 290 000 SEK from FCR-D upregulation and 160 000 SEK from FCR-D downregulation. For the summertime, bids can be placed for FCR-D upregulation throughout all hours of the day. FCR-D downregulation is more limited and is only possible between 06:00–15:00 meaning that income from the BESS during summer can be expected to 930 000 SEK from upregulation and 210 000 SEK from downregulation. In total, the annual income from this simulation is 1 600 000 SEK leading to a payback time between 5 and 7 years.

A bottleneck for the revenues is the grid connection of the facility. For example, bids for upregulation cannot exceed 503 kW even though there exists greater capacity throughout several hours of the day for both winter and summer. Similarly, FCR-D downregulation is limited by the grid connection as the available power that can be withdrawn from the grid is less than the power which the battery could be charged with. This is in line with Respondent 14 who pointed out that the grid connection can often be a bottleneck rather than the batteries when it comes to maximizing revenue from the balancing market.

Figure 13

BESS state of charge and grid utilisation throughout the day.



Note: The simulation is based on internal documentation of energy consumption combined with actual usage patterns of vehicles at DB Schenker.

Implementing a BESS today would entail that all available capacity could be used to participate in the balancing market as the current fleet does not require any further capacity to be used for charging. For the mentioned 1 224 kWh BESS, the available power for FCR-D down- and upregulation would be 326 kW and 503 kW due to limitations in the grid connection. The resulting revenue would equate to 1 700 000 SEK from FCR-D downregulation and 1 900 000 SEK from upregulation, respectively. The payback time would therefore fall in the range of 2 to 3 years, a significantly more attractive figure as compared to a scenario where vehicle charging is the primary objective.

6.4.3 Distribution terminal C – High electrification potential

The grid connection of Terminal C is the most powerful of the three case terminals analysed. Its maximum power output of 1072 kW means that on average a total of 10 200 kWh of energy can be used during the charging window when subtracting the terminal's consumption of 343 kW for miscellaneous activities. Seen over the entire day, the terminal has a total of 17 500 kWh available when excluding the energy required for all miscellaneous activities. As the average consumption from all vehicles would only amount to 6 155 kWh during the summer and 6 905 kWh during the winter, this terminal would have no issues with fully charging the entire fleet no matter the season. A BESS would therefore not yield any additional advantages when it comes to ensuring that vehicles are able to charge. However, if fast charging was to increase in the future that would require significantly higher peak power output compared to currently used chargers. In a case where several fast chargers were to be installed, the usage of BESS might become a necessity. This situation could for example arise if some of the partnering haulage firms would want to charge their vehicles at DB Schenker's distribution terminals.

While a BESS might not be needed for charging vehicles, it could still be used to generate income from flexibility markets. However, this would deviate from the original purpose and intended use with such a system. Therefore, it is important to make sure the investment would still align with DB Schenker's strategy and operational goals. If they were to move forward with such implementation, the BESS could be dimensioned to maximally utilize the current grid connection without being unnecessarily large, something that was not possible for the other two case terminals. In this case, it would result in a BESS with a size of 1 808 kWh where 1070 kWh would be dedicated for FCR-D upregulation and 738 kWh for downregulation. By operating the BESS solely for participating in the balancing market, a yearly revenue of 3 700 000 SEK could be generated from FCR-D downregulation and 4 000 000 SEK from downregulation. This would mean that the payback time would be between 1 and 2 years.

6.4.4 Aggregated case analysis

From the three terminals, it is evident that each one's characteristics affect the feasibility of BESS in different ways. For terminal A, BESS could seem viable at first glance. However, the terminal's limited grid connection stops BESS from solving the overarching issue. Even though BESS could provide some value in terms of more vehicles being able to charge, it is not economically justifiable, especially when considering the lifespan of the system. Terminal C on the other end of the spectrum highlights lucrative business opportunities but with limited value added to the ability to charge vehicles. As the initial purpose from DB Schenker was to gain resilience against grid shortages, BESS does not fill this gap for terminal C. More interesting is the case of terminal B, which exemplifies a scenario where BESS can excel. Here, it is shown that BESS can strike a good balance between helping to overcome peak power shortages while simultaneously generating income and helping the overall business case to become more attractive. Out of these three cases, it can therefore be concluded that terminal B is the most suitable case for an implementation of BESS with the purpose of gaining resilience while being able to recoup the investment cost.

Pivotal in the discussion for all cases is the estimated income from the balancing markets. As highlighted in empirical findings, calculating the investment outcome based on one single scenario constitutes a high risk. Especially so is the case when several of the respondents have agreed that prices are expected to drop with the introduction of more flexibility resources from battery parks and the emergence of V2G technologies. Like the padel courts in Sweden, a lucrative business opportunity could quickly turn into a resource not utilized as initially intended. All these economic uncertainties must be put in relation to the value of having a secure electricity supply for all distribution terminals. As stated in the empirical data, the cost of not having BESS will become clearer when the business is disrupted. Therefore, quantifying the effects of disruptions could be highly valuable for DB Schenker to include in the business case of BESS for distribution terminals, preparing them before the actual disruptions occur. Including this dimension helps to form the business case truer to reality.

As concluded in the analysis above, none of the case terminals have a current need for BESS to secure electricity supply. Implementing BESS could however still be relevant as the calculations showcase a highly lucrative business with attractive payback times, when solely using BESS for providing balancing services. Findings from Ingman and von Sivers (2023), promising 1–3 years of payback time for BESS investments, contradicts the findings for terminal A. Rather, they are more in line with the findings for terminal B and C where the BESS is not limited by the grid connection further highlighting the previously stated importance of dimensioning BESS based on the grid connection. By carrying out BESS projects near in the future, firms can also achieve learning opportunities and continuously build up the knowledge while also partaking in the balancing market to support financing of the BESS. This prepares firms for times when there is an actual need for BESS to being able to operate all electric vehicles.

7. Conclusion

This report aimed to investigate the feasibility of BESS for DB Schenker's distribution terminals to enable a continued electrification of their vehicle fleet. The findings provide a broad overview of the BESS landscape seen from the perspective of a large logistics provider. As more and more actors need to familiarize themselves with the electrification landscape, this report can help to give an overarching image of the complex network of actors, resources and activities involved. The findings are especially relevant to DB Schenker and other actors facing similar concerns by showcasing the possibilities and challenges BESS can offer. Furthermore, the findings show that implementation of BESS and its feasibility will differ considerably based on individual terminal settings, although, a general overview of the BESS landscape, with the actors, activities and resources involved has been identified. The network of actors is complex and consists of both established larger firms as well as smaller upcomers. The set of roles are continuously changing, and one actor may possess several roles simultaneously. Having the support of actors in your network is crucial for an efficient implementation of BESS, and especially so from those actors with high levels of power. A firm considering BESS must therefore carefully choose whom to partner with and which relationships to nurture the most. With each actor controlling some of the required resources, collaboration is essential.

The resources needed spans from purely physical to intangibles. There are several considerations that must be made when obtaining a BESS. Each choice is impacted by the purpose of the implementation as well as the synergy with already existing resources. In the case of a BESS in distribution terminals, factors such as sizing, battery type, and controlling systems all affects the realised value of the system. Our findings underscore that the value of a resource can change depending on the combination with others. For instance, implementing a BESS without a sufficient grid connection will highly limit its value both in terms of potential revenue and its ability to charge vehicles. Knowledge has also proven to be a central resource that can be developed in-house or acquired through collaboration. Having appropriate knowledge is detrimental for achieving a holistic perspective and allowing resources to be used at their maximum potential. In a situation with an absence of sufficient knowledge, managers must allocate time and effort to create actor bonds with knowledgeable actors in the network to leverage their expertise and bridge the knowledge gap.

The major activities identified in this report for implementing BESS can be categorized into several phases: decision making, exploring feasibility, gathering approvals, installation, and operation of the system. By mapping the activities in advance, they can better be coordinated, potentially reducing complexity and lead time of such a project. The findings highlight an absence of formalised activities where introduction of regulations may trigger new activities and standards to form. For the operational phase, balancing services are currently the most used and most lucrative activity. However, the findings indicate that the operational activities may shift in the future, prompting alternative use-cases of BESS.

When evaluating the feasibility of BESS, there are multiple key dimensions that needs to be considered. Firstly, the availability of physical space for safe installation and operation of

BESS is crucial. The fire hazard of a BESS was found to be a significant concern and must therefore carefully be considered when choosing the installation location. Additionally, having an energy infrastructure with compatibility and ability to handle increased power levels from BESS is a crucial circumstance that must be present. BESS becomes particularly feasible when there are fluctuations in energy demand, with periods of both scarcity and surplus, requiring the need to shift capacity over certain periods. In such a scenario, BESS emerges as a cost-effective alternative to otherwise being forced to upgrade the grid connection. Lastly, the affordability of BESS is a decisive factor, ensuring that the investment aligns with budgetary constraints and has a competitive payback time. The economic uncertainty is however identified to be major risk to the business case the primary income from BESS comes from a market characterized by large volatility and changes.

For managers wanting to investigate BESS for their operations, they must recognize the diverse landscape of actors, resources and activities involved and how they are interconnected. Given the critical role of knowledge identified in this study, managers must prioritize acquiring sufficient expertise through either internal development or external collaboration and strategic partnerships. In terms of policy implications, regulatory bodies play an important role in ensuring a smooth integration of BESS within new industry segments. In order to achieve this, there is a need to develop comprehensive guidelines that standardize the various activities involved in BESS implementation. By establishing clear and consistent requirements, these guidelines will provide certainty and guidance to all stakeholders involved in the process, ultimately accelerating the transition towards a more sustainable energy infrastructure.

7.1 Future research

From this study, several topics for future research has come to the surface. First, it would be interesting to explore the future regulatory landscape of BESS and what implications they may pose to firms considering an investment of BESS, as this research identified the regulators to have great impact in this network of actors. Second, a detailed mathematical model of how to optimise the activities of BESS with its various possible use cases and objectives would provide lots of value to more accurately allocate resources where it is best needed. Third, we believe the introduction of V2G can have great impact on the supply of flexibility in Sweden, affecting the business case of BESS. Meanwhile, it can also serve as a new business opportunity for logistics providers like DB Schenker considering the increasing number of electric vehicles entering their fleet. Diving into the matter of V2G’s impact on logistics providers would also be interesting for future researchers. Finally, this research was limited to the distribution vehicles. With the emergence of heavy-duty line haul vehicles, including them and their need for fast charging would provide additional value to this research field, exploring further applications of BESS.

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