On the road to grid stability

- Using batteries in heavy vehicles and charging infrastructure as frequency reserves

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LTH Faculty of Engineering

Division of Production Management

MIOM05 Degree Project in Production Management

Executive summary

Title: On the road to grid stability - A case study of using batteries in heavy vehicles and charging infrastructure as frequency reserves, to support the power grid

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Background:
Climate change and increasing threats that come with it fosters a need for changing from fossil sources of energy to renewable ones. Sweden aims to have net zero greenhouse gas emissions by the year of 2045. One of the sectors that need to take part in this shift towards fossil free energy is the transport industry. Electrification of vehicles is an important part of this shift. As a result, a large number of big batteries will be allocated within this industry. Apart from fuelling vehicles, batteries have a potential to be used for other purposes as well. Among others, batteries can be used as a frequency reserve, providing support services to the power grid.

Purpose:
The purpose of this master thesis is to investigate possibilities for using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid, and to investigate what value that can be created and obtained by these sites.

Research questions:
The research questions that this thesis aims to answer are the following:

- What actors within the transport industry have potential in delivering frequency regulation services?
    - What is the potential in different segments of the market?
    - What are the obstacles and enablers for electrification of the transport industry, and its possibility to provide support services with batteries?

    - What is the maturity level of the technology and the market, in particular in the relevant cases?
    - Which types of frequency regulation are most suitable for above mentioned actors and their prerequisites?
- How can the market for frequency regulation services be identified and characterised, and how can it be expected to develop during the coming years?
- What gaps are there to fill for actors interested in engaging in the market for support services?

Method:
The thesis was conducted as a case study in two steps, combining secondary data and statistics with expert- and stakeholder interviews. The method of the thesis takes on a descriptive and exploratory approach. First, the context in which the study takes place is described. Thereafter, a brief exploration and evaluation of a selection of potential cases was done. The evaluation led to a choice of three user cases, *overnight depot*, *logistics hub* and *solar park*, that were then further investigated, and analysed based on the research questions and the theoretical framework.

Delimitations:
The investigation of the thesis is limited to Sweden, and the Swedish energy system. The thesis only focuses on possibilities of providing frequency regulation with energy reserves. A selection of cases is chosen for the investigation, even though there might be potential in others as well.

Conclusion:
The thesis concludes that there is some potential in using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid. The most suitable types of frequency regulation that can be provided by a battery was found to be FCR-D, FFR, and to some extent FCR-N. Sites providing frequency regulation creates value in terms of stability of the power grid, and additional revenues for the sites. The three investigated cases all had both potential and some limitations to their ability to provide frequency regulation.

The overnight depot, with either buses or trucks, has good potential with regard to both aggregated capacity at the site, as well as available hours. With electrification of the vehicle fleet, some transport companies have found a need for increasing the utilisation rate of their electric trucks. Increased operation hours lead to a loss of potential for providing frequency regulation. For a logistics hub, the biggest potential for frequency regulation was found in supporting infrastructure, and buffer batteries in particular. The third case investigated a more holistic energy system, with a site that combines solar power, with energy and charging for vehicles. Together, these components give synergy effects, and the case shows a good potential in providing frequency regulation and renewable energy to the grid, as well as other values in terms of increased electrification. The thesis further concludes that the changing frequency regulation market and energy system creates opportunities for new value creation and capture.

Keywords: *Case Study, Electrification, Frequency regulation, Energy reserve, Battery, Heavy vehicles, Vehicle-to-grid*

Preface

This master thesis is written at the department for production management at the Faculty of Engineering at Lund University as the final project of a Master of Science within Industrial Engineering and Management. This thesis was done during one semester, and therefore corresponds to the workload of 30 credits each for the authors, marking the end of a five years of education, worth 300 credits. The thesis is done in collaboration with E.ON E-mobility in Malmö, who formulated the foundations to the questions the thesis aims to investigate, and provided great support along the way.

First and foremost, we would like to express our gratitude towards our supervisor from Lund University, Ola Alexanderson. Thank you for all your support and guidance, as well as your engagement and willingness to discuss and help.

We would also like to give a big thank you to our supervisor Peter Andersson at E.ON E-mobility. Thank you for your work in helping us find relevant subjects for the interviews and for all our interesting discussions, your valuable input and for your commitment and optimism. We would also like to give thanks to everyone at E.ON who has made us feel welcome and who has provided help and inspiration.

Finally, we would also like to give thanks to all interviewees that took the time to participate in our interviews and give us input and expertise. Your answers to our questions were greatly appreciated and valued. Without your involvement this thesis would not have been possible to carry out. We hope the findings and results of this thesis might be of interest for some of you as well.

Lund, May 2023

Matilda Kjellström and Caroline Wuttke

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1. Introduction

In this chapter the background, purpose and focus and delimitations of the thesis are presented. Also, the research questions that this thesis aims to answer are presented, together with research areas.

1.1 Background

The threat that climate change poses to humanity and our planet has created an urgent need to replace old fossil-based energy sources with renewable sources. Sweden aims to have net zero emissions of greenhouse gases by the year of 2045 (Energimyndigheten, 2023a). To achieve this goal, the transport sector, among others, needs to replace fossil fuels with electricity (Regeringskansliet, 2021).

In Sweden the year 2021, about 60% of the total produced electricity came from renewable sources (Statistikmyndigheten SCB, 2022). Renewable energy sources are for example wind, water, and solar energy. The allocation between the different renewable energy sources is the following: 43% waterpower, 17% wind power, and 1% solar power. Sweden is making further investments in renewable energy. According to the Swedish Energy Authority, the production of wind and solar power in Sweden is prognosed to increase steadily between the years 2020 and 2024 (Grahn, 2022). Wind and solar power are intermittent energy sources, which means that they cannot be controlled and are thus more difficult to keep the production at an even level (Mlilo et al., 2021).

For the electricity grid to function as planned it needs to be in balance (Svenska kraftnät, 2021a). There are many factors that can affect the balance of the system and cause chain reactions and instability. There are three main variables that need to be stable to be able to achieve a stable system. These three are: Frequency stability, Voltage stability and Rotor angle stability. All of these are important for the function of the electrical system, and they therefore need to be balanced in different ways.

Increased electrification in various parts of society, alongside an increased share of intermittent energy, and disturbances affect the stability and capacity of the power grid (Interviewee 3 (Senior Commercial Business Developer at E.ON), 2023). The challenge to maintain the stability of the grid fosters a need for stabilising services (Svenska kraftnät, 2023a). Many different actors see a potential in providing such services to the power grid, and according to Svenska kraftnät (2023b), it can provide a significant monetary benefit to incorporate those in one's business. The service to help maintain the frequency of the power grid is called frequency regulation. According to Interviewee 1 (2023), E-mobility manager at E.ON, there are several sources that can be used for this purpose, called frequency reserves, one being energy storage in the form of batteries.

The market for lithium-ion batteries as energy storage is growing rapidly and is expected to do so over the coming years within several sectors, such as energy companies, transport and vehicles, industries, real estate and venture capital (Svenska kraftnät, 2022a). One factor driving this increased demand is the ability to offer support services to Svenska kraftnät, as frequency reserves.

According to Svenska kraftnät (2022a), about 90% of installed batteries will be located in vehicles. Integration of electric vehicles with the power grid is an important part of making the electrified transport system work efficiently (Jain et al., 2021). To help stabilise the power grid, a battery can both take up energy, stop charging or feed back energy to the grid (Interviewee 1). The concept of feeding back energy from the vehicle to the power grid is called Vehicle-to-Grid (V2G). V2G can create new opportunities for smart power grids, with a potential to both support the local power grid, optimise usage, and support Svenska kraftnät with frequency regulation (Power Circle, 2020). For transport companies, investments in electric vehicles are costly as it is today, and thus additional revenues could come at hand (Interviewee 1). However, what effect this feedback has on the durability and lifespan of the battery is not yet completely explored (Interviewee 1; Svenska kraftnät, 2022a).

There are also many challenges that come with electrification, both related to the infrastructure, technologies, and also stakeholders and roles (Interviewee 1). Electrification of vehicles in specific, comes with requirements on charging infrastructure and new technologies. The increased use of electricity for charging vehicles puts demand on the stability and capacity of the power grid (Energimyndigheten, 2022a).

Electrification of heavy vehicles, such as buses and trucks require both big batteries in the vehicles, and establishment of charging infrastructure, both at their home sites and alongside roads (Interviewee 1). Since such a large share of installed batteries will be found within vehicles, this means that there is potential for aggregation of battery capacity at various sites within the transport industry. These batteries might have available capacity during certain hours of the day, which have potential to be utilised as frequency reserves. The shift towards renewable energy and electrification fosters a more holistic and integrated view on the energy system, which opens up possibilities for new solutions and forms of value creation and exchanges of value. This lays the ground for this thesis.

1.2 Purpose

The purpose of this master thesis is to investigate possibilities for using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid, and to investigate what value that can be created and obtained by these sites.

1.2.1 Research questions

The research questions that this thesis aims to answer are the following:

- What actors within the transport industry have potential in delivering frequency regulation services?
    - What is the potential in different segments of the market?
    - What are the obstacles and enablers for electrification of the transport industry, and its possibility to provide support services with batteries?
    - What is the maturity level of the technology and the market, in particular in the relevant cases?

    - Which types of frequency regulation are most suitable for above mentioned actors and their prerequisites?
- How can the market for frequency regulation services be identified and characterised, and how can it be expected to develop during the coming years?
- What gaps are there to fill for actors interested in engaging in the market for support services?

1.3 Focus and Delimitations

The thesis will focus on the Swedish market. However, the Swedish power grid is a part of the Nordic power grid system.

The focus of this thesis is heavy vehicles and transport-related sites which have energy storage that has a potential to function as frequency reserves. In this thesis only energy storage in the form of batteries will be considered.

This thesis will solely focus on the user cases in the context of frequency reserves, even though there might be a business case for using the battery for other alternative activities that have a potential of creating value. In literature, it sometimes varies what services that are included in the term support services, but in this thesis, the term support services include: FCR-N, FCR-D, FFR, aFRR and mFRR. Furthermore, the terms frequency regulation and frequency regulation services will be used throughout this thesis and also refers to mentioned support services.

This thesis will focus on three user cases that later are used to draw implications about the market. After three cases with potential are chosen, focus will be on them, even though there might be other cases with potential as well. When referring to “potential”, the term has been broken down into six factors: the size of the individual energy storage, the accumulated size of potential market, the accumulated size of realised market, predictability, the time that the energy storage is connected to the power grid and maturity of technology. Other factors were excluded from this thesis when the potential was considered.

In the analysis, only a number of components will be chosen from the different presented theories and models since those are the ones that are within the scope of this thesis. In the stakeholder mapping, a number of stakeholders will be identified and analysed using the power/interest matrix. The mentioned stakeholders are thus not necessarily all stakeholders, but it is a selection of the ones that were brought up in the cases and the ones that influence the research questions. Regarding the analysis of the business model, a selected number of interesting components were analysed.

1.4 Thesis outline

Chapter 1- Introduction

In this chapter the background, purpose and focus and delimitations of the thesis are presented. Also, the research questions that this thesis aims to answer are presented, together with research areas.

Chapter 2- Methodology

This chapter explains the methodology used in the production of this thesis. The research strategy and approach are described together with motivation of the choices of methodology. The different sources of data, and the choices behind them are presented, as well as validity and reliability of the chosen methodology.

Chapter 3- Theoretical background

In the third chapter the theoretical background that is needed to analyse the findings are presented. The theoretical background includes theory about the components of business models and maturity of technology. Moreover, the stages of diffusion of an innovation are described, as well as theory behind stakeholder mapping and value network analysis.

Chapter 4- Setting the context

In chapter four, the context of the thesis is described. This chapter aims to give the reader an understanding of the environment and conditions in which the investigation of the thesis will take place. This gives the reader the knowledge needed for the investigation and the discussion that follows. The content of this chapter is a description of how the Swedish power grid works, the need for balancing of the grid, the market for support services, an explanation of the different support services, technical prerequisites for providing support services and policies and regulations affecting the electrification of the transport sector.

Chapter 5- Results and analysis

This chapter presents the process and evaluation of potential cases, that leads to a choice of three cases. These will be the focus of the rest of the thesis. The chapter goes on to present the findings from the chosen cases, as well as an analysis of each case based on the theoretical framework.

Chapter 6- Discussion

The sixth chapter discusses the findings and analysis of the cases based on the research questions presented in chapter one.

Chapter 7- Conclusion and implications for future research

In chapter seven, conclusions based on the discussion and analysis are drawn, and reliability and validity of the thesis is discussed. Contributions to research, as well as suggestions for future research are also presented.

Chapter 8- References

In chapter eight, an alphabetic list of all used references is presented.

Chapter 9- Image sources

In this chapter the sources from which images and graphs have been taken or adapted are listed.

Chapter 10- Interviewees

Chapter ten contains a list of all persons that have been interviewed for the thesis. Each interview is numbered and a description of the role and expertise of the person, as well as the company for some interviewees, are presented.

2. Methodology

This chapter presents the research strategy and approach, as well as chosen research methods of the thesis. It further describes how the data collection will be made and how the choice of method affects the validity and reliability of the thesis.

2.1 Research strategy and approach

To reach the aim of a research project, one needs to have a strategy to do so (Denscombe, 2010). Demscombe further describes that a strategy for research needs three components, an overview of the project, a plan of action and a goal. The goal of this thesis is to investigate possibilities for using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid, as well as to investigate what value that can be created and obtained by sites with energy reserves. The method of a research project is described by Höst et al. (2006) as a series of steps moving the thesis forward from an overall aim towards the goal. According to Höst et al., the method should be chosen with regard to the aim and goal of the thesis, which can have either of the following natures:

- Descriptive, with the aim to describe the way in which something is or is done.
- Exploratory, with the aim to obtain a deeper comprehension of the way in which something is or is done.
- Explanatory, with the aim to explain causations and why something is the way it is, or is done the way it is done.
- Problem solving, with the aim to solve an identified problem.

First, a descriptive method will be used in chapter 4, *Setting the context*, to describe the setting and underlying factors regarding the electricity grid, frequency regulation, policies and regulation, and more, that need to be understood before the thesis investigation can be conducted and before the research questions can be answered. Since the goal of this thesis is to obtain a deeper understanding of several current and future aspects of the possibilities and limitations for services connected to frequency reserves, this thesis can be considered exploratory. The main method will be a case study of three different cases, which is described by Höst et al. as an appropriate method for a master thesis, and implies that one or several cases are thoroughly studied without influencing the cases. A case study can give a deeper understanding of a specific topic and it is a flexible method that can be dynamically changed during the process of the case study. It is further described that interviews are a common method for collecting data in a case study.

Höst et al. goes on to describe different tools for collecting data and analysing the findings. According to Höst et al., the data that is collected can be of either qualitative or quantitative nature. Qualitative data is more descriptive, using words and sentences, whereas quantitative data consists of numbers and other measurements. Höst et al. describes that for complex questions and research problems, both types of data are often used, and this will be the case for this thesis. In this thesis, qualitative data will be collected primarily from interviews and literature review. Quantitative data will to some extent be collected from interviews, but also from statistical websites and literature review.

2.2 Choice of cases

Denscombe (2010) describes good practice when choosing cases as follows: "*A case study should be chosen deliberately on the basis of specific attributes to be found in the case - attributes that are particularly significant in terms of the practical problem or theoretical issue that the researcher wants to investigate.*"

The choice of case was done based on six factors of significance to the investigation of the purpose and research questions of this thesis, affecting the relevance of the cases. These factors are:

- The size of the individual energy storage
- The accumulated size of potential market
- The accumulated size of realised market
- Predictability
- The time that the energy storage is connected to the power grid
- Maturity

These factors are significant for the investigation of possibilities for using batteries in heavy vehicles and charging infrastructure at sites as energy reserves, to support the power grid. A number of potential cases were found through a discussion with interviewee 1, and desk analysis. These cases were then evaluated based on these criterias. To be able to make this evaluation, data was collected from both statistical websites, government authorities' websites, articles and information sheets. The size of the energy storage was evaluated based on the size of a single battery, and the size of the potential accumulated market based on number of potential possible suppliers. The size of the accumulated realised market was evaluated based on the actual number of actors that have adopted the enabling technologies. The predictability was evaluated based on the possibility of knowing when the energy storage will be connected to the grid and have available capacity. Finally, the maturity was evaluated based on the extent of electrification and use of batteries for each case. Since a few of the cases have very similar attributes, these were grouped together. Finally, three cases with good potential were selected and further investigated.

According to Denscombe (2010), a case can be used in different ways. One common way of choosing a case is to choose a typical one. This means that there are other cases that are similar that could have been chosen, and that this similarity makes the results applicable to a bigger population. This was applied when choosing the interview subjects for the three cases.

2.3 Literature review

A literature review was done to identify the background leading to the research question and to set the context of this thesis. This was done using both sources from Swedish authorities, statistical websites, other websites, and materials belonging to relevant actors, information sheets and scientific papers. The scientific papers were found using different databases such as *LUBsearch* and *Google scholar.* Relevant articles were found by systematic use of relevant search words connected to the topics of interest. Furthermore, relevant papers were found by tracing back theory to its original authors by using the references in found papers. When possible, as recent literature and data as possible was used to increase validity of the source. The literature review primarily generated data for the background and the chapter setting the context. For the case study, there was a limited number of scientific papers that covered the research questions, and interviews was thus the focus of that data collection.

2.4 Interviews

To collect data regarding the context, background and the three cases, several interviews with expertise within different areas were conducted. According to Höst et al. (2006), interviews can be held in three different ways, depending on the questions. The interviews were held as open directed interviews, which, according to Höst et al. means that open ended questions are asked based on topic, using an interview guide. This method is often used for exploratory research. First, an interview guide with the intended questions was written, and sent to the interviewees, and then the interviews were held accordingly. The questions were formulated based on the research questions and what additional information that was needed to properly set the context and understand the background. The questions were categorised under different topics and taken in an order that was suitable based on the responses.

Interviews can be both recorded via audio, and notes can be taken during the interview to remember what was found most interesting. The interviews were held over Zoom or Microsoft Teams. Notes were taken systematically during the interviews, and the interviews were also recorded for later analysis and improvements of notes.

Interviewees for the three different cases and the background was chosen to complement each other, providing a more holistic understanding of the different cases. The same interview guide was used for interviewees within the same area, but the order of the questions and the focus of the interview varied a bit based on the nature of the responses and the interviewees' knowledge of the different areas.

2.5 Validity and reliability

According to Höst et al. (2006), reliability is obtained through accuracy in the data collection and analysis. The connection between the object that is investigated and the measurements that are used for said investigation gives validity (Höst et al., 2006). Using different methods to study the same object can also increase validity. For all cases and the setting of the context, data was gathered both from a literature review and interviews with relevant stakeholders and experts. Validity was in this thesis also seeked through both the choice of cases, where first a number of cases were investigated with regard to their potential, and then graded according to a red- and green light system based on set criterias, to find the cases with the most potential. Moreover, within the chosen cases, several different stakeholders, with various characteristics were interviewed. This was done to include several perspectives and to increase the external validity, making the results more applicable on a general level. The extent of the validity will be limited to what is included within the scope of this thesis, hence the results might be invalid for populations and circumstances that are excluded in chapter 1.3.

Furthermore, according to Höst et al. (2006), validity of exploratory research can be increased by conducting interviews or dialogues with relevant stakeholders regarding the findings. In this thesis, the findings were validated through interviews with interviewee 1, Business Manager eMobility, E.ON, and with interviewee 17 (2023), an expert in e-mobility at Power Circle. Moreover, findings were compared with similar research projects from various interest groups.

Regarding reliability, all interviews and the analysis of the collected data have been done by two students to minimise the risk of misinterpretation. Also, as was described above, notes were taken during all interviews, and they were also recorded to be able to re-listen to make sure the concepts were understood correctly. Additional clarifying questions were also asked to some interviewees at a later time to make sure concepts were understood correctly, and at some times, deepen the understanding further. Each interview guide with the questions that were asked during each interview will be presented in the appendix. The findings are presented and analysed in chapter 5, based on the theory presented in chapter 3. A discussion on validity and reliability will be conducted in chapter 7.

3. Theoretical framework

To be able to perform an analysis of the findings, a theoretical background is needed. The purpose of this master thesis is to investigate possibilities for using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid, and to investigate what value that can be created and obtained by these sites. Therefore, the relevant theoretical framework for this thesis will be theory regarding the components of a business model and the Business Model Canvas, maturity of technology, diffusion of innovation, stakeholder theory and mapping, and value networks.

3.1 Business models

3.1.1 Definition of Business model and its components

The “Business Model” is a somewhat fuzzy concept with several different definitions (Fielt, 2014). Basically, it can be said that every company has a business model, regardless of whether it is officially articulated or not. The term was introduced in the early 70s and was widely spread during the shift to the digital economy in the 90s. The definition of the concept has been thoroughly debated and there is not yet one general accepted definition. Osterwalder and Pigneur (2010, p.14) define a business model as “A business model describes the rationale of how an organisation creates, delivers, and captures value”, and that is the definition that will be used throughout this thesis.

3.1.2 Business model canvas

To develop a business model, Osterwalder and Pigneur (2010) presented the Business Model Canvas (BMC). This framework can be used for both analysing, development of, and also illustration of business models. The canvas consists of nine building blocks which are described below according to Osterwalders and Pigneurs’ definitions.

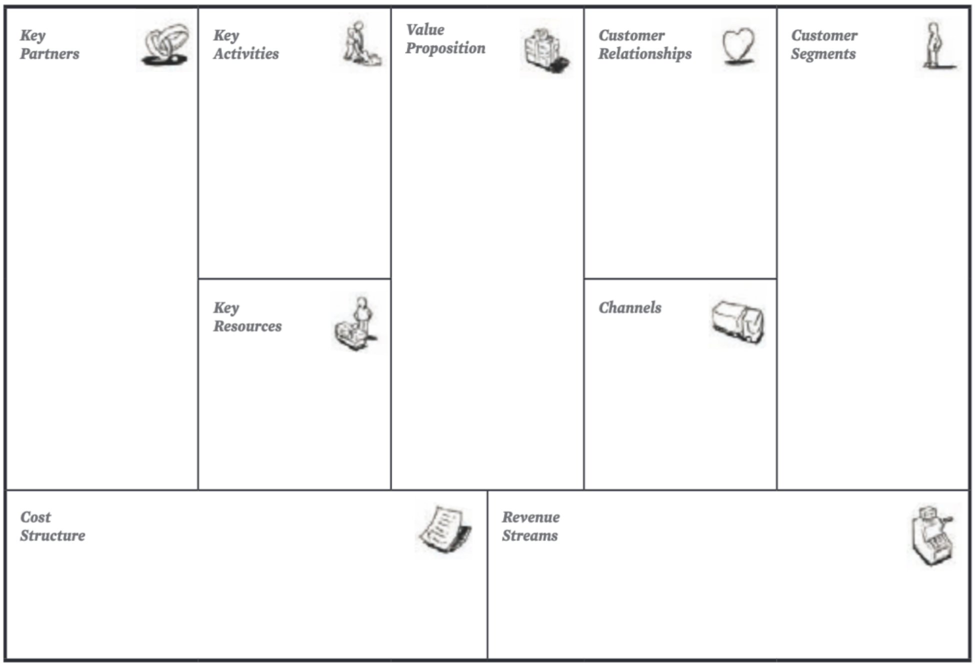

Figure 1. The Business Model Canvas (Osterwalder and Pigneur, 2010).

Customer Segments

The customer segment is one or more customers that the organisation provides with their service or products. A customer segment consists of actors that are alike, behave in a similar way and have similar needs. When creating a BMC, either one or more customer segments of various sizes can be chosen. The choice of which customer segments to direct one's services or products to is very important, and impacts how the rest of the BMC is designed.

Value Proposition

The value proposition aims to solve a problem or facilitate something for the customer, as well as to meet the needs of the customer. The value proposition can consist of different elements that together make up the bundle that together offers value to customers. The value proposition can both be something new that no other actor can offer, or a new way of combining existing elements to create value.

Channels

Channels refers to the mix of elements through which the value proposition is delivered to customers. This includes both channels for interaction, delivery, and sales. Management of channels is substantial for the customer experience, throughout the customer journey.

Customer Relationships

Customer relationships refers to the relations that are built between the organisation and their different customer segments. The ways in which the organisation keeps up, and develops these relationships is also an important part of customer relationships.

Revenue Streams

The revenue streams are incomes coming from customers as a result of delivering the presented value proposition. This can be both from single purchases, and also ongoing payments, depending on the nature of the value offer.

Key Resources

Key resources refers to the things that are needed to perform above listed elements. The resources can be divided into both physical, intellectual, financial and also human resources.

Key Activities

Key activities are the activities performed by the organisation to fulfil above listed elements and successfully deliver to customers and function as an organisation. Key activities can be both connected to production, network or platform, and solving problems for customers.

Key Partnerships

Key partnerships are built between the organisation and external actors, that provide services or products which are not made by the organisation itself. Partnerships can have various characteristics, and Osterwalder and Pigneur list the following four types (2010, p. 38):

1. Strategic alliances between non-competitors

2. Coopetition: strategic partnerships between competitors
3. Joint ventures to develop new businesses
4. Buyer-supplier relationships to assure reliable supplies

Cost Structure

The cost structure is derived from the other parts of the business model canvas, all described above. Looking at the cost structure, it can be value- or cost-driven, or of different nature.

3.2 Technology theory

3.2.1 Diffusion of innovation and crossing the chasm

To understand how innovations are adopted by users, the Technology Adoption Life Cycle (TALC) presented by Rogers (2003) can be used. The framework divides customers into five segments: innovators, early adopters, early majority, late majority and laggards, see figure 2. The division is done depending on customers' purchase patterns and behaviours.

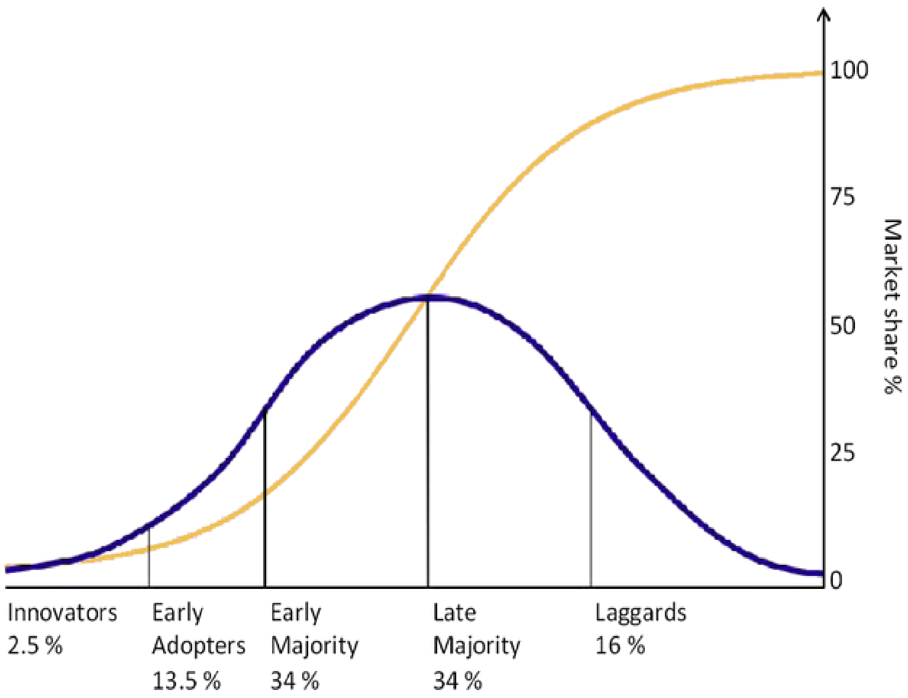

Figure 2. Diffusion of innovations, where the blue line represents the successive adoption of different customer segments, and the yellow line represents the total market share. (Wikipedia, 2023).

Innovators

Innovators are the ones really passionate about innovations. This segment must be able to handle a great deal of uncertainty and also accept that not all new innovations will be a success. Also, some understanding and ability to set complex technology into a context is of use for an innovator. This segment plays an important part in bringing new innovations into new settings.

Early Adopters

Meanwhile innovators are a more isolated group, acting on their own, the early adopters are more closely connected to other actors. How this segment adopts new innovations sets an example for the following segments, providing them with information and guidance. Early adopters can help an innovation to go from a small scale to reach a majority.

Early Majority

The early majority is a small step ahead of the late majority in adopting new innovations, as they are more likely to adopt a new technology, without wishing to take the lead in such a shift. This segment needs a little more time to fully accept an innovation and is one of the larger segments.

Late Majority

This segment refers to actors that are a little slower in their adoption process than the average actor and might be a result of economic or other external factors. The late majority has a more reserved way of taking regard to innovations, and their adoption is dependent on how the innovation is received by the earlier segments.

Laggards

The laggards are the last to adopt an innovation and can be seen as a bit more isolated and less dependent on previous segments. This group looks to the past when making decisions, and are sceptical to change, in some cases due to lack of resilience to failure. This means that the group wishes to see that an innovation is a success before they dare to invest in it.

3.2.2 Crossing the chasm

Moore (2014) presents a theory called “crossing the chasm”, that refers to a chasm between early adopters and early majority. According to his theory, it is not always easy for an innovation to move between these stages. Moore further presents an approach to cross the chasm and successfully get adopted by the majority. According to Moore, choosing a niche-market to focus all efforts on at first does not come naturally to the sales-driven, but is an important enabler for success. The company should aim to have market leadership early on, in a small number of segments, since being a leader in a market attracts pragmatists. This choice of niche market should be done in a smart manner, so that access to other niches close to the first one is then easily provided.

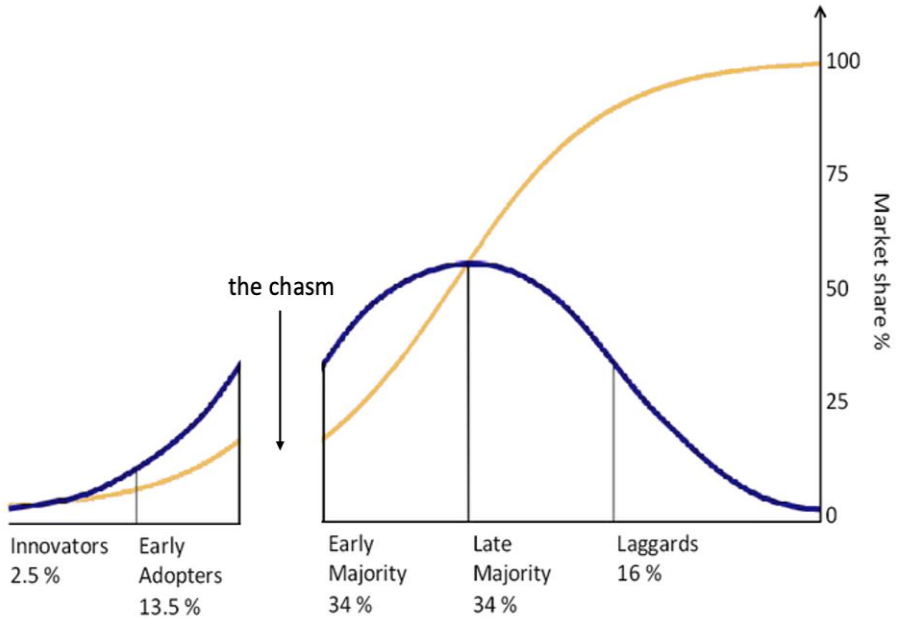

Figure 3. A remake of figure 2 (Wikipedia, 2023), showing the chasm.

3.2.3 Maturity of technology and the S-curve

To illustrate the sales life cycle of a product, the S-curve is a frequently occurring model in literature (Michelfelder and Morrin, 2005). According to the theory, the sales rate of new buyers is slow in the very beginning, then increases and goes fast over a period of time, then slows down and with time decreases towards zero. The S-curve is connected to the diffusion theory and the different adoption categories, see figure 2. Far to the left of the S-curve, in the beginning, the purchases are done by the innovators, and to the very right the purchases of the laggers are found, see the yellow line in figure 2.

When commercialising a new technological innovation, there are many factors determining whether it will be a success or a failure (Chiesa and Frattini, 2011). For example, timing is of the essence. Chiesa and Frattini lists three factors regarding timing that can determine the outcome of a commercialisation:

- Timing of the innovation’s launch on the market
- Timing of the innovation’s preannouncement
- Timing for establishing partnerships and alliances

If the timing is not right in regard to the development of customers’ technologies, it can be challenging to get them to adopt the new technology. Gourville (2006) describes that companies often are very optimistic regarding innovations, meanwhile customers are a bit more sceptical and might not see the benefits that the company sees from the innovation. According to Gourville, customers tend to stick to what is familiar, and might need help in adopting new technologies. It is therefore of importance that the company understands potential reasons for scepticism and try to adjust for those. One way of helping customers adopt a new technology is to make the need for change in behaviour as little as possible. That way, the company can counteract resistance.

Ford (1988) presents several aspects that can be examined when evaluating an organisation's technologies and how they relate to competing actors and technologies. According to Ford, there is a high probability of an organisation having a superior knowledge of a technology when it is new, but as times goes, the gap between the organisation’s knowledge and the customers’ knowledge shrinks. As technology matures and other actors increase their knowledge of it, the profit margins become smaller and other actors can start doing the same thing (Ford, 1988). Innovation can then be a way to stay ahead of competitors, both through offering new products or services, or a new way of bundling those (Ford and Thomas, 1997).

3.3 Stakeholder theory and mapping

There are many definitions to be found of what a stakeholder is, and the majority shares in most senses the same meaning. One definition of stakeholders by Freeman et.al (2018) follows: *“Stakeholders are groups and individuals that have a valid interest in the activities and outcomes of a firm and on whom the firm relies to achieve its objectives”.* Stakeholders can be found both within and outside a company and can vary in importance and influence (Johnson et al., 2008).

Johnson, et al. (2008) presents a division of external stakeholders into three groups based on the characteristics of the relationship between the stakeholder and the actor in question, and thus how the different stakeholder can affect the outcome of the actor's strategy:

- Economic stakeholders, which includes distributors, suppliers, competing actors, and shareholders.
- Socio/political stakeholders, which includes governments, and actors behind policies and regulations.
- Technological stakeholders, which includes standard agencies, different important customer groups, competitors and other actors that have influence over the market and the rate of adoption of new technologies.

Depending on the situation, the three stakeholder groups can be expected to have varying effects on the actor.

To better understand the roles and influence of different stakeholders, a stakeholder mapping can be conducted (Johnson et al., 2008). Stakeholder mapping can be done with a *power/interest matrix*, see figure 4. This matrix takes regard to two dimensions, the *power* of the stakeholder and the *level of interest* of the stakeholder. Power refers to the strength and extent of their influence, and level of interest refers to the extent to which the stakeholder has interest in either supporting or opposing the strategy of the actor. The matrix which is used for stakeholder mapping shows the nature of the relationship that is typically formed with different types of stakeholders, based on their power and level of interest, see figure 4. For example, stakeholders in group D, *key players*, have both high power and interest. These stakeholders and the relationship with them are of great importance and should be managed with care. Johnson et al. present some examples of actors that can be found in group D: major investors or shareholders, government or funding agencies.

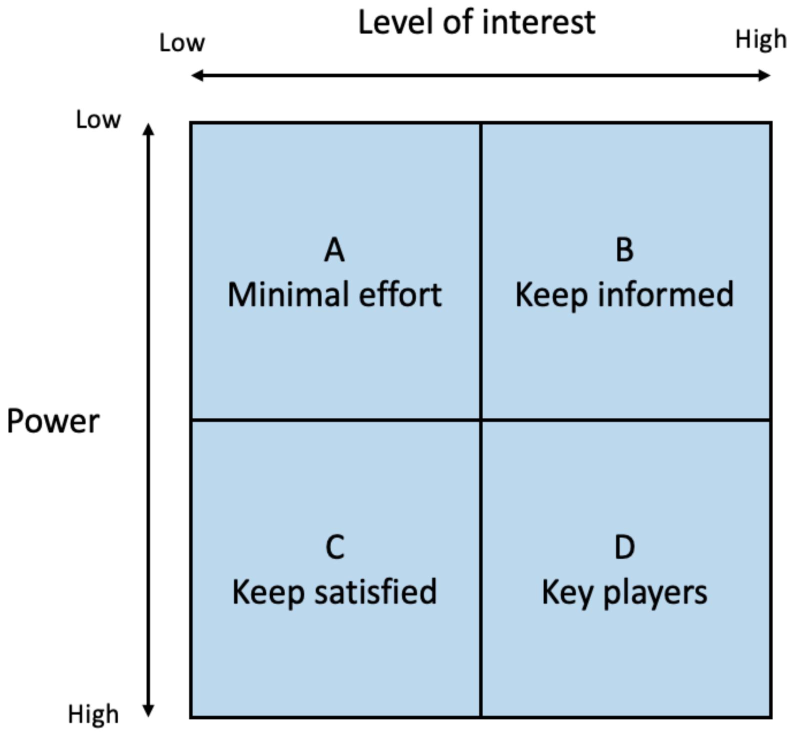

Figure 4. Power/interest matrix, remade from Johnson et al. (2008). The matrix is used for categorising stakeholders based on the two dimensions power and level of interest.

3.4 Value networks and value creation

Traditionally the process of value creation has been described through the value chain, a model rooted in the thinking of an industrial production line.

Porter (1985) defines value as "*the amount buyers are willing to pay for what a firm provides them*". Porter means that the goal of any company strategy is to create value for buyers that exceeds the cost of doing so. The process of creating value can be displayed through the value chain (Porter, 1985). The value chain consists of value activities and margin. Value activities are the activities a firm performs through which a product valuable for the buyers is created. The margin is defined as the difference between the total value, and the cost of performing the value activities. The value activities can be categorised into primary activities and support activities, where the primary activities can be categorised into five different categories: *inbound logistics, operations, outbound logistics* and *service*. The support activities are *firm infrastructure, human resource management, technology development* and *procurement.* The primary activities are activities connected with the creation and sale of the product, as well as the transfer of the product to the customer and the after-sale service. The role of the support activities is to support the primary activities, as well as the other support activities. According to Porter (1985) support can be in the form of technology, purchased input, human resources, and other functions.

Verna Allee (2000) means that this model needs to be replaced with a new way of thinking. She means that instead of thinking in the linear, and industrially focused, way of the value chain, the process of value creation should be observed, and thought of, as a network. Allee (2009) calls this type of network a value network, and defines it as: *"any purposeful group of people or organizations creating social and economic goods through complex dynamic exchanges of tangible and intangible value"*. The value network can create both internal value and external value. Allee (2000) claims that any organisation could be understood and considered as a value network.

According to Allee (2009) a value network generates economic value through exchanges between several actors, such as one or several organisations, its customers, partners, suppliers and community. The transactions that are conducted between these parties are not only traditional transactions regarding goods, services and revenue, but also transactions of knowledge and intangible value.

To be able to create a strategy based on a value network, the network first needs to be mapped out (Allee, 2008). This mapping is made to understand the value exchanges in the network. Allee defines a method for this mapping, consisting of three elements. The three elements of the mapping are roles, deliverables and transactions.

1. The first element, roles, refers to the participants in the network that contributes to, and carry out functions in the network. These participants can be single individuals, different kinds of groups or units, whole organisations, or entire industry groups or communities. What defines a participant in the network is the ability to add value, take action, engage in interaction and make decisions.
2. The second element, transactions, are activities with a direction. It represents something that is exchanged between two roles in the network. The transactions can be of tangible resources such as product or revenue, or exchanges of more intangible resources such as information and benefits.
3. The third element are deliverables, which is the actual “product” that is exchanged between the roles. The deliverables can be of both physical (for example goods or documents) or non-physical character (such information or expertise).

When the mapping has been performed and the roles, transactions and deliverables have been identified, the information found in the mapping can be used to further analyse the value network. Similarly to the mapping process, the analysis consists of three elements. Allee (2008) identifies these elements as the following:

1. Exchange analysis- In this step the pattern of exchanges and value creation in the network is assessed. Furthermore, the health of the network is assessed, together with the capabilities for value conversion in the network.
2. Impact analysis- In the second step of the analysis, an assessment of what impact the value input has on the roles in the process of value realisation.
3. Value creation analysis- This step examines how value can be extended, created, and leveraged in the best way. This can be done in different ways, value can be added, extended to other roles, or converted to another type of value.

3.5 Summary of theory

Together, the theory and models presented, will be the framework for the analysis which aims to find answers to the research questions presented in the purpose of the thesis.

The Business Model Canvas will be used to analyse what actors in the transport industry have a potential in delivering frequency services, as well as to analyse what the potential in the different segments in the market is. Furthermore, the BMC will also be used to analyse some of the changes that can be expected in the market during the coming years, in regard to a number of relevant components in the BMC.

Different parts of technology theory will be used to analyse several of the research questions. Together with the BMC, an analysis of the maturity of technology in different sectors will help answer the question of what actors within the transport sector have potential in delivering frequency regulation services. Theory of maturity of technology and diffusion of innovation will also be an important part of identifying obstacles and enablers for electrification, as well as analysing the level of maturity of the market. The theory behind diffusion of innovation and maturity of technology will also be used in order to create an idea of how the technology, and as a result, the market, might be expected to develop during the coming years.

In order to identify important actors in the path towards electrification and development of the market for frequency regulation services, stakeholder theory and mapping will be used. Identifying and categorising stakeholders is one important part of the analysis in order to answer the research questions about obstacles and enablers, as well as new roles and gaps to fill.

Theory about value networks and value creation will be used in order to analyse synergies in value creation, and possibilities for collaboration. Therefore, value network theory will be an important part of analysing enablers and obstacles for electrification, as well as new roles and gaps on the market.

When combining these components of theory, the comprehensive theoretical foundation needed to be able to analyse the research questions can be achieved.

4. Setting the context

In this chapter the relevant context for the thesis is explained. The purpose of this chapter is to provide an understanding for the relevant environment and conditions for the thesis, to give the knowledge needed for the further investigation, analysis and discussion that follows.

4.1 The Swedish electricity grid

The Swedish electricity grid is divided into three different levels: the transmission system, the regional grids and the local grid (Energimyndigheten, 2022b). The highest level is the transmission system. Through the transmission system electricity is transported from the big producers of electricity out to the regional grids, and also in between the different grid areas in Sweden. The transmission system is managed by the public authority Svenska kraftnät, which is the authority responsible for the Swedish power grid and the maintenance and development of the transmission system (Svenska kraftnät, n.d). This makes Svenska kraftnät a so-called TSO (transmission system operator).

The transmission system operates at a high voltage (usually between 400-220 kV) (E.ON, 2022). When shifting from the transmission system, down to the regional grid, this high voltage is converted into a lower voltage (usually 130-40 kV). The regional grids transport the electricity from the transmission system to the local grids. Big consumers of electricity are usually directly connected to the regional grid, as well as some middle-sized electricity production sites, like wind parks (Svenska kraftnät, 2022b). In Sweden, the regional grids are operated and owned by five different regional grid companies (E.ON, 2022). From the regional grids the electricity is transferred to the local grids, from which it is delivered to users like households and companies (Svenska kraftnät, 2022b). This is the last step of the delivery of electricity to consumers. The voltage in the local grids is usually 40 kV or lower. On the way to the households the voltage is then further lowered to 230 V. Small producers of electricity can also be connected to the local grids, for example households that sell their surplus production. There are over a hundred small and big companies that manage and own local grids (E.ON, 2022).

For the electricity grid to function as planned it needs to be in balance (Svenska kraftnät, 2021a). There are many factors that can affect the balance of the system and cause chain reactions and instability. There are three main variables that need to be stable and in balance to be able to achieve a stable system. These three are: Frequency stability, Voltage stability and Rotor angle stability. All of these are important for the function of the electrical system, and they therefore need to be balanced in different ways.

4.2 Keeping the system stable

To maintain a stable electricity system, different services can be used. There are different services that can be used for keeping the three factors mentioned above (Frequency stability, Voltage stability and Rotor angle stability) in balance.

Voltage stability is the ability of the power system to keep the power grid at stable voltages, as well as the ability to be able to find a new equilibrium after disturbances (Svenska kraftnät, 2021b). Achieving voltage stability is an absolute necessity for a power system. The power grid is designed to function for a certain interval of voltages, which means that too high or too low voltages can have serious consequences for the system. Having too high voltages can cause both damages on facilities and humans, and too low voltages can lead to energy losses at the point of transfer, lower transfer capacity and even collapse of voltage. Therefore, it is important to be able to adjust the voltage in both directions, both up and down. These regulations need to be done quickly and continuously, and therefore the power grid needs to have automated regulators to control and adjust the voltage.

Rotor angle stability refers to the ability of the generators in a power system to stay synchronised, i.e the rotor angle stability depends on how the rotor angles of different generators relate to each other (Svenska kraftnät, 2021c). If the rotor angle of one generator differs too much, in relation to the others, there is a risk that one or several generators loses synchronisation with the rest and will be disconnected from the system. When the system is exposed to disturbances, the rotor angles may change, which can cause big fluctuations in effect between the different generators. If these fluctuations become too big, there is a risk that it might lead to the collapse of the system. It is therefore important to keep the generators synchronised with each other. Rotor angle stability is mainly reached through measures to dampen the mutual movement between the rotors of the generators.

Frequency is measured in Hertz (Hz) and is a wave vibration which transports energy (Svenska kraftnät, 2021a). In the context of the power grid, the frequency relates to the velocity of rotation in the generators that generate electricity (synchronous generators). Frequency stability refers to the power grid's ability to keep at a stable frequency after disturbances in the balance of production and consumption. The frequency stability is mainly affected by three different factors: the size of the imbalance, the availability of stabilising resources and the characteristics of the power system. To have a functioning electricity grid, the frequency must at all times lie in between a very narrow interval (Svenska kraftnät, 2021d). For the Nordic power grid to function, it must be kept at a frequency of 50 Hz. Achieving frequency stability in the power grid can be quite complicated, and depending on the situation, different types of support services can be used. These different ways of controlling the frequency of the power grid will be further described in section 4.3.

4.3 Different types of frequency reserves

Depending on the cause of the imbalance and the nature of the disturbance, different means to stabilise the frequency can be used (Svenska kraftnät, 2021e). This is done with the help of so-called frequency reserves. Svenska kraftnät uses three different types of support services for frequency stability, depending on the need and the situation. Svenska kraftnät mainly acquires the reserves from different electricity market actors, through bidding on the balance market (Svenska kraftnät, 2023a). The three different types of frequency reserves are:

- Frequency Restoration Reserves (FRR)
- Frequency Containment Reserves (FCR)
- Fast Frequency Reserves (FFR)

The Frequency Restoration Reserves refers to two types of restoration reserves, one automated and one manual, with the task of restoring the frequency to 50 Hz. With the help of a control signal, the automated reserve (aFFR) is activated automatically when the frequency differs from 50 Hz (Svenska kraftnät, 2023c). The Manual Frequency Restoration Reserve (mFRR) also has the task of restoring the frequency to 50 Hz, but this type of FRR is activated manually by Svenska kraftnät and is meant to relieve the automated support services (Svenska kraftnät, 2022c).

The term Frequency Containment Reserves includes three different kinds of frequency reserves (Svenska kraftnät, 2023a). The first kind is FCR-Normal, which is the frequency reserve used during operations as normal. It is a symmetrical form of both upwards and downwards regulation and is automatically activated when the frequency of the powergrid lies between 49,90-50,10 Hz.

To protect the power grid from frequency imbalance caused by disturbance, the frequency reserve technology called "Frequency Containment Reserve – Disturbance" (FCR-D) is used (Svenska kraftnät, 2023a). This regulation can be done in two ways; either upwards (upward FCR-D) or downwards (downward FCR-D), depending on the nature of the imbalance. Upwards FCR-D is automatically activated when the frequency lies within the interval of 49,90-49,50 Hz, and downwards FCR-D when the frequency lies within the interval of 50,10-50,50 Hz. The reserve needs to have a minimum endurance of 20 minutes, which means that there must be enough capacity in the reserve to be able to be constantly activated for 20 minutes.

The last type of frequency reserve, FFR (Fast Frequency Reserve), is used as a remedial action to compensate for quick changes in the frequency of the power grid (Svenska kraftnät, 2021f). This action is done in short cycles of a couple of seconds at a time. FFR is automatically activated when steep changes in frequency are caused by low levels of rotational energy. The endurance of FFR needs to be either 30 seconds or 5 seconds depending on the agreement, and it needs to be ready to be used again within 15 minutes.

According to interviewee 3, many sources of energy can be used as frequency reserves, but depending on the type of frequency reserve that is needed, different sources are more or less suitable. One important factor that determines which source of energy that is suitable for the type of frequency reserved, is the activation time. The shortest activation time is demanded from the types of frequency reserves that are used to stabilise in the case of a disturbance (Svenska kraftnät, 2023a). These are upwards and downwards FCR-D and FFR. The provider of FCR-D needs to be able to deliver 50% of the agreed upon number of Watts within 5 seconds, and 100% within 30 seconds. For FFR there are different requirements regarding activation time depending on how big the deviation of frequency is. The bigger the deviation, the quicker 100% of the capacity is needed. When the frequency is 49,50 Hz, 100% needs to be activated within 0,7 seconds, by 49,60 Hz it is one second, and by 49,70, it is 1,3 seconds. In comparison, aFFR requires an activation time of 5 minutes for 100% and mFFR 15 minutes for 100%. FCR-N, which is used during operations as normal, requires an activation time of 63% within 60 seconds and 100% within three minutes.

As of now, the majority of the frequency regulation services bought by Svenska kraftnät is provided by suppliers of waterpower (Svenska kraftnät, 2023d). According to interviewee 12 (2023), a senior market analyst at one of Sweden’s biggest waterpower suppliers, one of the main reasons for the dominance of waterpower within the supply market is tradition. Historically, in the last decades, Sweden’s biggest power sources have been waterpower and nuclear power. Though nuclear power theoretically also could be used to provide some support services, waterpower is better suited for such operations due to the complexity of the nuclear process.

One challenge that waterpower is facing in regard to support services is the short activation time required for some of the services (interviewee 12). When using waterpower for providing frequency regulation services, there will always be a certain time lag between the detection of the imbalance and the availability of the capacity. Depending on the nature of the imbalance the waterflow through the power plant needs to be either increased or reduced, something that according to interviewee 12 always will take a couple of seconds. Because of this time lag, waterpower cannot be used to provide FFR, since the required activation time is too short for the waterpower to be able to respond quickly enough. As of now, waterpower can still fulfil the requirements for providing FCR-D, which also has a short activation time, compared to other types of frequency reserves. However, according to interviewee 12, changed requirements for activation time, something that Svenska kraftnät has plans to implement (Svenska kraftnät, 2023e), can lead to the waterpower plants having a hard time being qualified to deliver FCR-D.

FFR	FCR-D upwards	FCR-D downwards	FCR-N	aFRR	mFRR
Fast Frequency Reserve	**Upward Frequency Containment Reserve- Disturbance**	**Downward Frequency Containment Reserve- Disturbance**	**Frequency Containment Reserve-Normal**	**Automatic Frequency Restoration Reserve**	**Manual Frequency Restoration Reserve**
Upwards regulation	Upwards regulation	Downwards regulation	Symmetrical upwards and downwards regulation	Upwards and/or downwards regulation	Upwards and/or downwards regulation
Smallest volume of bid 0,1 MW	**Smallest volume of bid** 0,1 MW	**Smallest volume of bid** 0,1 MW	**Smallest volume of bid** 0,1 MW	**Smallest volume of bid** 1 MW	**Smallest volume of bid** 10 MW (5 MW in SE4)
Activated when: Automatically when the frequency changes due to low rotational energy in the system	**Activated when:** Automatically activated when the frequency is between 49,90-49,50 Hz	**Activated when:** Automatically activated when the frequency is between 50,10-50,50 Hz	**Activated when:** Automatically activated when the frequency is between 50,10-49,90 Hz	**Activated when:** Automatically when the frequency deviates from 50,0 Hz	**Activated when:** Manually on request from Svenska kraftnät
Activation time: 100% within: 0,7 sec (by 49,50 Hz) 1,0 sec (by 49,60 Hz) 1,3 sec (by 49,70 Hz)	**Activation time:** 50% within 5 sec 100% within 30 sec	**Activation time:** 50% within 5 sec 100% within 30 sec	**Activation time:** 63% within 60 sec 100% within 3 min	**Activation time:** 100% within 5 min	**Activation time:** 100% within 5 min
Endurance 30 sec or 5 sec Repeatable within 15 min	**Endurance** At least 20 min	**Endurance** At least 20 min	**Endurance** 1 h	**Endurance** 1 h	**Endurance** 1 h

Figure 5. Information about the different kinds of frequency reserves. Translated and adapted from Svenska kraftnät (2023a).

4.4 The Balance market

Svenska kräftnät is the actor responsible for keeping the electricity grid stable (Svenska kraftnät, 2021g). To achieve this, the kind of stabilising services as mentioned above, are needed. The stabilising services are acquired by Svenska kraftnät through the so-called balance market. On the balance market, all actors that fulfil the requirements for delivering such services can sell their reserves to Svenska kraftnät. There are also certain rules and regulations for how the trade on the balance market should be conducted. It needs to be done in an open, cost efficient and non-discriminatory way.

There are also certain rules and requirements that need to be met by the suppliers, for them to be allowed to deliver services on the balance market to Svenska kraftnät (Svenska kraftnät, 2022d). To be allowed to sell support services to Svenska kraftnät, suppliers first have to go through a pre-qualifying process (Svenska kraftnät, 2023f). In this process the supplier has to do an application and complete certain tests, which then will be evaluated by Svenska kraftnät. Suppliers have to go through a separate pre-qualification process for every type of service they would like to deliver, and they also need to redo the qualification process every five years, or if the technical specifications or requirements are changed. Once the supplier has shown that they can fulfil the requirements of the service they want to provide, and have been qualified, they are allowed to place bids on the balance market.

When selling support services, the supplier commits to being able to deliver an agreed upon number of watts during an agreed upon amount of time (interviewee 4). This means that the supplier, during this time, has to have enough available resources to be able to deliver what has been agreed upon. When supplying frequency reserves used to compensate for disturbances (FCR-D and FFR), it is not certain that the resource will need to be activated. The supplier needs to be stand-by for the period of time that is agreed upon with Svenska kraftnät, and have the resources available, but if no disturbances occur, the reserve does not need to be activated. For these services, the supplier gets paid for the amount of time it is ready to supply the reserve, not the amount of times the reserve is activated.

To make sure that this is fulfilled there is a need for a Balance responsible (Svenska kraftnät, 2022d). To be able to deliver reserves to Svenska kraftnät, the supplier either has to be balance responsible themselves, or they need to make a deal with another company that will be balance responsible instead of them, since there always need to be a balance responsible. The balance responsible is the part that is responsible both for the planning aspect, but also the business aspect of the balance in the power grid. The balance responsible should plan on an hourly basis the needs of their customers, and if this plan is not successful, i.e., balance is not achieved, the balance responsible must pay the costs for restoring the balance. Hourly, the plan for the need of the next hour is handed over to Svenska kraftnät, and Svenska kraftnät then makes sure the system is in balance in real time.

According to Svenska kraftnät, the role of balance responsible is going to change in 2024 (interviewee 4). As the character of the power grid changes because of a shift in energy sources and new technology, the need for support services that balances the power grid becomes bigger and bigger (Svenska kraftnät, 2022d). To enable more suppliers to be able to deliver balancing services (such as frequency reserves), and to encourage competition, the role of balance responsible is going to be split into two new roles. The new roles will be Balance Responsible Party (BRP) and Balancing Service Provider (BSP). The BRP will be economically responsible for the costs that stems from imbalances, while the responsibility of the BSP lies within providing the services used for balancing the grid, such as FCR, aFFR and mFFR for example. Through this change Svenska kraftnät hopes to see an increase in the number of BSPs.

4.5 The energy mix and inertia of the power system

The electricity produced in Sweden mainly stems from five different sources: water power (43%), nuclear power (31%), wind power (17%), thermal power (9%) and solar power (1%) (Statistikmyndigheten, 2022). In 2021, approximately 60% of the produced electricity in Sweden came from renewable sources. Wind power was first introduced in Sweden in 1993, and has since then had a steady increase in the number of GWh produced per year and is now the third biggest source of power in Sweden (Statistikdatabasen, n.d). Solar power was first introduced in the Swedish energy mix in 2011, and has also since then had a steady increase in the number of GWh produced per year. Ten years after the introduction, solar power now accounts for 1% of the total electricity produced in Sweden. This shift towards more renewable and intermittent power sources affects the functions and properties of the power grid. Intermittent power sources have different properties than the plannable power sources that traditionally have been used, and for which the functions of the power grid are adapted (Karlsson, et al., 2016).

The frequency of the grid depends on the rotor speed of the rotating parts of the power system (Karlsson, et al., 2016). The power system absorbs and emits energy, which results in an increase or decrease in frequency. The system has a certain inertia, which is the resistance against changes in speed and motion. Since the goal is to maintain a stable frequency, the goal is to create a system with high inertia. Inertia in the power grid is naturally created by the production of power through water- and nuclear power plants, since the electricity is created with the help of big and heavy turbines, which is a natural source of inertia. This type of inertia that is constructed into the system is called the inertial response of the system.

The electrical grid, as all systems that rely on a balance between inflow and outflow, needs to be controlled to stay stable (Karlsson et al., 2016). In all kinds of controlling processes there always be some kind of delay between the recognition of an imbalance and the implementation of controlling actions. To be able to keep the grid in balance during this lag, some kind of buffer is needed. In the electrical grid, the inertial response fulfils this role most of the time. The rotating generators are rotating with the speed that corresponds to the electric frequency, and therefore works like a storage of kinetic energy, which can act as a quick buffer in the case of imbalance in the system.

Now, when the production of electricity shifts more and more from plannable consistent power sources, such as water and nuclear, to intermittent weather reliant power sources, it has consequences for the inertial response of the system (Karlsson et al., 2016). These types of renewable energy sources, like wind and solar power, do not possess the same ability to intermediate store kinetic energy that the rotating generators do. Less use of heavy generators, and more use of power sources that do not add to the natural inertia of the system, leads to less total inertia in the system. This reduction of the buffer that the inertial response provides, means that the response time of the controlling functions that balances the system needs to be shorter.

Since the shift towards renewable energy sources like wind and solar power, neither of which creates inertia in the system, tends to increase in pace and become a bigger share of the total energy mix, new ways to keep the system stable and to replace the loss of inertia the old energy sources contributed with are needed. When the inertial response of the system decreases, something else that can cover for the necessary time the system takes to restore the system after imbalances is needed.

4.6 Requirements on the infrastructure of chargers and batteries in regard to support services

4.6.1 Requirements for a battery to be able to act as a frequency reserve

Using a battery as a frequency reserve can be done in different ways, but one of the most common and modern ways to do it according to interviewee 3 is with the help of three components. The first component is a local electricity meter with the ability to measure the frequency of the power grid. The meter is connected to the same power grid connection as the battery, and with the help of this measurement of frequency, the meter detects when the battery needs to be activated.

The electricity meter is connected to a local control unit, a gateway, which is connected to the internet. The gateway is controlled by a cloud-based control system for batteries, known as an Energy Management System (EMS). Within the EMS, there is often a module, called a Virtual Power

Plant (VPP). The VPP aggregates several batteries, and makes bids on the balance market, based on the aggregated capacity. If the bid is accepted, the information about during which hours the battery needs to be on stand-by for providing capacity in case of a deviation of frequency is sent back to the gateway, which then controls the battery in real-time. When the electricity meter detects a deviation in frequency during the time for which the bid was accepted, the gateway controls the battery so that it reacts accordingly and either discharges or charges, and hence regulates the frequency upwards or downwards.

4.6.2 Requirements for flexibility services via vehicle-to-grid

Batteries and chargers used for electrical vehicles have to comply with certain standards. One of these standards is ISO 15118 (ISO, 2022). ISO 15118 sets a standard for the communication between an electric vehicle and the charging equipment. One part of ISO 15118 that is particularly interesting from a flexibility point of view is the functions for enabling electrical vehicles to be utilised as energy resources. This allows the battery in the vehicle to provide power back to the grid, and hence enables vehicle-to-grid connections. The term vehicle-to-grid (V2G) is defined in the ISO 15118 standard as: *"plug-in electric vehicle interaction with the electric grid, including charging as well as discharging and bi-directional communication interface"*. This means that all batteries and chargers that comply with the ISO 15118 are, from a technological point of view, able to perform vehicle- to-grid connections. When V2G connections are enabled, this allows for the battery in an electrical vehicle to be used for services (Interview 1).

4.7 Policies and regulations to limit global warming

The shift towards more sustainable power sources and fuels is an urgent topic. To reach the goals regarding emissions and pollution that have been set to limit global warming, the world needs to continue to make the shift from fossil fuels to renewable power sources. In the Paris Agreement, goals were set by the UN to keep the average increase of temperature as a consequence of global warming, below 2 degrees Celsius (European commission, n.d). As one part of reaching this goal, the EU and its member states have committed to a binding target of a reduction of greenhouse gas emissions by 55% by 2030, compared to 1990.

To support the market in this shift, governments and governmental bodies, as well as unions and trade organisations, can establish regulations or subsidies, or other instruments to create incentives for the market to move in the desired direction (Eklund, 2017, p. 223). Taxation and fees can be used to restrict the usage of something that is considered to have negative external effects, through an increase in price. Governmental instruments can also be used the other way around, to encourage the usage of something considered to have positive effects, by lowering the price through subsidies.

4.7.1 Policies and regulations regarding traffic, fuels and vehicles

As a step in reaching the goal of climate neutrality by 2050, the European parliament has decided upon a ban on selling new personal cars and vans fueled by fossil fuels by 2035 (Europaparlamentet, 2023). This would mean that after 2035 all new cars that are produced must be fueled by renewable fuels. The new rules were agreed upon by the parliament and the EU-member countries in late 2022, and in February 2023 they were approved by the parliament. The last step of the process is that the new rules also formally need to be approved by the European council.

A third of Sweden's total greenhouse gas emissions stems from domestic transports (Sveriges miljömål, n.d). As a part of Sweden's strategy to reach net-zero greenhouse gas emissions by 2045 (Sveriges miljömål, 2022), the Swedish government has decided that greenhouse gas emissions stemming from domestic transports (domestic aviation excluded, since it is a part of the European Union Emissions Trading System) should be reduced by 70% by 2030 compared to the levels of 2010 (Regeringskansliet. n.d).

One of the areas where these kinds of instruments can be seen is the taxation of fossil fuels in Sweden (Skatteverket, 2023). This "fuel-tax" is a combination of both taxation of carbon dioxide emissions and taxation of energy. This means that a tax is added to the price of the fuel, making it more expensive, and thus hopefully, less attractive to the customers. This tax is applicable to all fossil fuels used as fuels for engines (with some exceptions).

One initiative that works for increased sustainability through subsidies, is Klimatklivet, an investment program created by the Swedish government (Regeringskansliet, 2022). All types of organisations and companies, apart from private individuals, can apply for support for investments that lead to decrease in carbon dioxide emissions. Funds are primarily given to those investments that result in the biggest decrease in carbon dioxide emissions per invested SEK. So far, Klimatklivet has approved 5102 applications for investments for a total of 13 billion SEK (Naturvårdsverket, n.d). Out of those approved applications, 2640 were for charging stations, 252 had to do with vehicles and 232 with transports. On average, the funds from Klimatklivet covers 41% of the total investment cost. To enable further investments in charging stations and infrastructure for electrification, the Swedish government has decided to increase the funding for Klimatklivet with another 400 million SEK for 2023 (Regeringskansliet, 2022). The funding will then further increase with 500 million SEK per year for both 2024 and 2025 to enable further expansion of the infrastructure for electric vehicles and transport.

4.7.1.1 Subsidies for electrification of buses

To encourage the switch from fossil fuels to renewable fuels in public transport, the swedish government has introduced the so-called electric bus bonus (elbusspremie) (Energimyndigheten, 2023b). The bonus is available for actors who operate within the public transport, and should be applied for before the purchase of an electric bus. The purpose of the bonus is to cover some of the difference of cost between a purchase of an electric bus and a bus run by fossil fuels, and through this increase the number of electrical buses in traffic. The goal is to reduce emissions of greenhouse gases and noise pollution, and hence contribute to a better climate. Actors purchasing buses for public transport can get 20% of the price of the electric bus as a bonus paid from the Swedish energy agency, as long as the 20% is not more than a 100% of the difference between the price of an electric bus and the price of the closest comparable diesel bus. When buying plug-in-hybrid buses, actors can get half of the bonus amount. If an actor is not buying for public transport, but for private traffic companies, then 40% of the difference of the price of the electric bus compared to the diesel bus can be paid as a bonus.

4.7.1.2 Regulations and subsidies for electrification of trucks

As a way to speed up the electrification of the transport of goods in Sweden, the Swedish energy agency started the initiative "Regional electrification pilots" (Regionala elektrifieringspiloter) in 2022 (Energimyndigheten, 2022c). The aim of the program is to increase the number of charging stations for electricity and hydrogen gas across Sweden, to enable a shift towards more sustainable transports. The Swedish energy agency will distribute 1 543 million SEK to actors who have applied to be part of the initiative and that are able to have charging stations up and running by the autumn of 2023.

4.7.1.3 Regulations and subsidies for electrification of maritime traffic

As of now, there are not any subsidies that are specifically aimed at electrification of maritime traffic, though several are being discussed and investigated (Trafikanalys, 2022). In 2022 the Swedish government gave Trafikanalys the mission of investigating what instruments could be used to increase the rate of electrification of maritime traffic, which resulted in a report with several suggestions. Maritime traffic is also included in both the taxation of fuel and Klimatklivet, mentioned in section 4.7.1. Since reduction of the carbon dioxide emissions from the transport sector is crucial to reach the goals regarding levels of carbon dioxide emissions for the future, Klimatklivet encourages more applications regarding electrification of maritime traffic, and sees a big potential for reduction of emissions within the sector (Naturvårdsverket, 2022). Klimatklivet has previously given 5,2 million SEK to DFDS Seaways for investments in enabling electrical charging of a Roll-on/Roll-off vessel in the port of Gothenburg.

5. Results and analysis

In this chapter the findings from the data collection will be presented together with an analysis based on the previously presented theoretical framework. The first part of the chapter presents findings regarding batteries, suitable types of frequency regulation and the market for frequency regulation. These findings are based on interviews and secondary data. Thereafter, the process through which the user cases were chosen is presented. Then, each of the three chosen cases will be investigated. In the beginning of each case, the findings from the interviews and secondary sources will be presented. This will then be followed by an analysis of each case based on the models and theory in the theoretical framework. The last part of the chapter is an analysis of the three cases together from a business model point of view.

5.1 Battery life span and second life for batteries

A discussion on battery life span and second life for batteries from heavy vehicles was conducted with an expert in batteries in heavy vehicles and second life (Interviewee 13, 2023).

According to interviewee 13, there are two ways in which a battery can age. First, there is the calendar ageing, which means that the battery gets old in terms of time. This happens after 10 to 20 years. To have batteries fueling heavy vehicles is a rather new thing and it has thus not been tested fully to drive these for a full calendar lifetime, and its calendar ageing is therefore not well explored yet. The second type of ageing is connected to charging cycles. The pace of ageing can vary depending on both how fast the battery is charged and discharged, and how deep the cycles go. Since the transport industry in general wants a very high utilisation on their electric vehicles, the lifespan of a battery in a heavy vehicle can then be expected to be shorter than 10 years.

From the discussion with interviewee 13 it was understood that there is a great potential in using the capacity that is left in a vehicle battery after it is considered consumed. According to interviewee 13, a battery still has around 80 % of its capacity left when it is considered consumed by industry standards. This means that there is a lot of capacity left in the battery and still many possible applications for the battery after this point. One of the most common applications is energy storage. This can then serve as a frequency reserve, on the frequency regulation market, which is, according to interviewee 13, the by far most lucrative market in Sweden for a second life battery right now. Other applications can be peak-shaving, arbitrage on the electricity market, store leftover energy from wind or solar power, and more.

If worn out batteries are to be extracted from vehicles and made into an energy storage, the batteries need some adjustment (Interviewee 13). Then, a number of batteries can be built together to get a desired capacity, alternatively be aggregated via some service. A market for second life batteries is starting to develop, but it is a quite new and unexplored area that needs further research.

5.2 Suitable types of frequency regulation

The focus of this thesis is, as previously mentioned, providing frequency regulation services with the help of energy storages in the form of batteries. During the interviews it was found that even though batteries in theory can perform all different kinds of frequency regulation services, some types are more suitable and beneficial based on the characteristics of the battery (interviewee 1; interviewee 3; interviewee 4 (Responsible for the Balance Market, Svenska kraftnät), 2023; interviewee 12). As previously mentioned, different types of frequency regulation services have different requirements in regard to activation time. Compared to many other sources of energy, batteries can deliver the frequency regulation services with very short notice (interviewee 3; interviewee 12). Since FFR and FCR-D have the shortest activation times, these are the markets that are the most interesting for batteries as energy sources. Since the barriers of entry in regard to activation time are the highest for these markets, and batteries have the possibility to reach these requirements, it opens up an opportunity for batteries to be competitive on these markets.

Another factor that favours FFR and FCR-D as services for batteries to perform is the usage pattern these types of frequency regulation services entail. According to interviewee 3 and Interviewee 5 (2023), expert in solar parks with batteries, the usage pattern for FFR and FCR-D wears less on the battery, compared to the usage pattern of FCR-N, aFRR and mFRR. When providing FCR-N, mFRR and aFRR the battery is activated for a much larger share of the time for which the service has been sold. In the case of FFR and FCR-D, the battery is only used in the case of disturbances and often only during a couple of seconds. Since the lifespan of a battery is affected by the number of charging cycles it goes through, a more frequent use will affect the life-span of the battery more than a less frequent one.

The opinion that batteries, as of today at least, are best suited for providing FCR-D and FFR is also shared by Svenska kraftnät, as mentioned in their development plan for 2022-2031 (Svenska kraftnät, 2021h, p.25).

In this thesis, batteries with a main purpose that is not frequency regulation will be investigated. This purpose can for example be to fuel a vehicle or to provide charging to vehicles. This affects which types of frequency regulation that are suitable for the battery to provide. To be able to regulate both upwards and downwards the battery needs to have the capacity to both charge and discharge over a period of time (Interviewee 3). Therefore, it is preferably kept at approximately 50% charged. If the battery is desired to be kept fully charged, then it can only be used for upwards regulation, which means that it feeds back electricity to the grid. At fully, or almost fully charged, there is no room in the battery for regulation downwards.

Regarding frequency regulation with second life batteries, FFR, FCR-D, and FCR-N are of interest (Interviewee 14 (Environmental and quality officer, Ystad hamn), 2023). FCR-N is a more energy intensive form of frequency regulation, which leads to more wear, but in regard to second life batteries, that is not necessarily a drawback. Depending on point of view, it can be a good thing to use up all the capacity of a battery within the calendar lifetime, so that it is not thrown away with capacity left.

5.3 The market for frequency regulation services

5.3.1 The market for support services historically and in the present

As stated in the chapter above, the frequency regulation services that are most suitable for batteries are FFR and FCR, and therefore this investigation of the market will focus on these types of frequency regulation.

Svenska kraftnät is the only customer in Sweden today that purchases frequency regulation services (Interviewee 3). For both FCR-D and FFR, there is a fixed maximum volume that is bought by Svenska kraftnät. The maximum volume of FCR-D is based on the total dimensioned error in the Nordics, which is then divided on the TSOs of the Nordic countries (Svenska kraftnät, 2021h). This brings the maximum volume of upwards FCR-D up to 558 MW and downwards FCR-D to 538 MW (Svenska kraftnät, 2023g).

The calculations of the error for upwards FCR-D are based on that the nuclear reactor Oskarshamn 3 is in full operation (Svenska kraftnät, 2023h), and according to correspondence with experts at Svenska kraftnät, the need for upwards FCR-D will not change unless the error becomes bigger or smaller. As long as the criterion is based on Oskarshamn 3, the volume will remain the same. The same principle goes for downwards FCR-D, for which the error calculations are based on that one of the foreign cables Nordlink or NSL are in full operation (Svenska kraftnät, 2023i).

The maximum volume of FFR needed is based on the amount of rotational energy that the Nordic power grid needs to ensure that the frequency will not fall below 49,0 Hz (Svenska kraftnät, 2021h). The current maximum volume that is set for FFR is 100 MW (Svenska kraftnät, 2023g).

The last couple of years, the Swedish market for support services has grown bigger and bigger in terms of monetary value. In 2021, Svenska kraftnäts net cost for support services was 2678 million SEK, which was an increase of 1623 SEK compared to 2020 (Svenska kraftnät, 2022e). This was followed by an even bigger increase in 2022, when Svenska kraftnät's net cost for support services was 6650 million SEK, which was an increase of 3022 million SEK compared to the previous year (Svenska kraftnät, 2023g, p.59). This is a big increase compared to previous years. Between 2014 and 2017 the yearly cost was between 500 million SEK and 1000 million SEK (Svenska kraftnät, 2021i). Between the years 2018-2020, the yearly cost remained relatively steady at between approximately 1000 million and 1500 million SEK. According to Svenska kraftnät, the main reason for the big increase in costs the last two years was the rising price of electricity and increased volatility of the market (Svenska kraftnät, 2022e; Svenska kraftnät, 2023g).

5.3.1.1 FCR

Out of the 6650 million SEK spent on support services in the year 2022, 4529 million SEK was spent on frequency restoration services (FCR-D and FCR-N) (Svenska kraftnät, 2023g, p.85). In 2021, the costs for frequency restoration reserves amounted to 2678 million SEK (Svenska kraftnät, 2022e, p. 66), out of the 3628 million spent on support services in total (Svenska kraftnät, 2023g, p. 59). In the graph below (figure 6), the distribution of costs between FCR-D and FCR-N for the years 2017 to 2021 can be seen, as well as a forecast made by Svenska kraftnät of the years 2022-2025 (Svenska kraftnät, 2022f). But as can be seen in the graph, the prognosis for 2022 is not accurate compared to the actual outcome. This is something that should be considered when observing the prognosis for the coming years. It should also be noted that FCR-D in the outcome part of the graph only refers to FCR-D upwards, since FCR-D downwards was first introduced on the market in 2022.

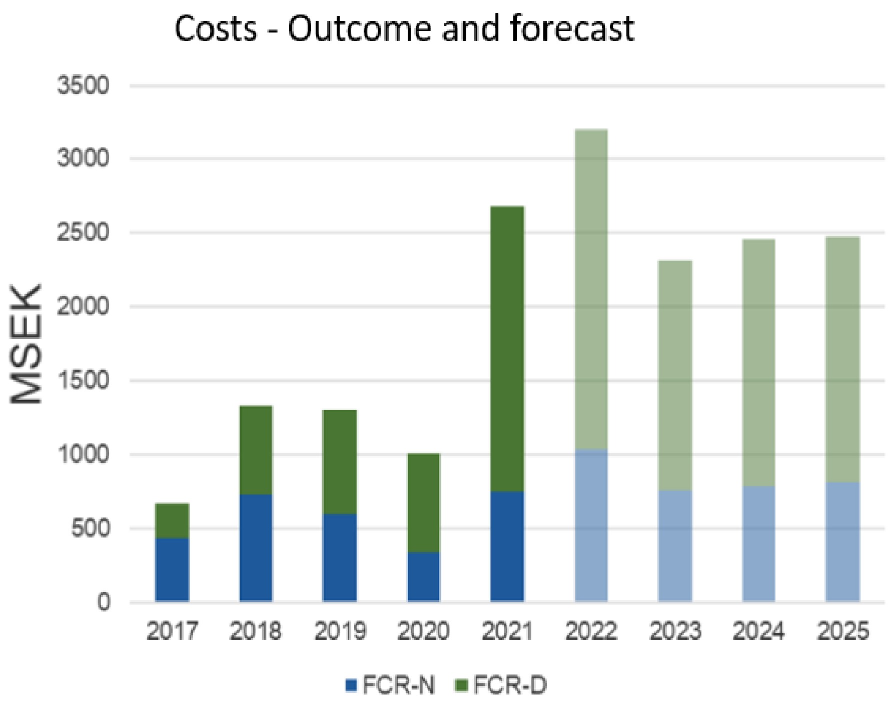

Figure 6. Costs for FCR- outcome and forecast translate from Svenska kraftnät (2022f).

The price of the individual bids on FCR that were accepted, is not available for the public, but Svenska kraftnät has published the graph below of the volume weighted average prices of FCR-D and FCR-N in 2021 (graph 7). It can be seen in the graph that the price can vary a lot over a year, and that the prices for both types seem to follow one another relatively closely.

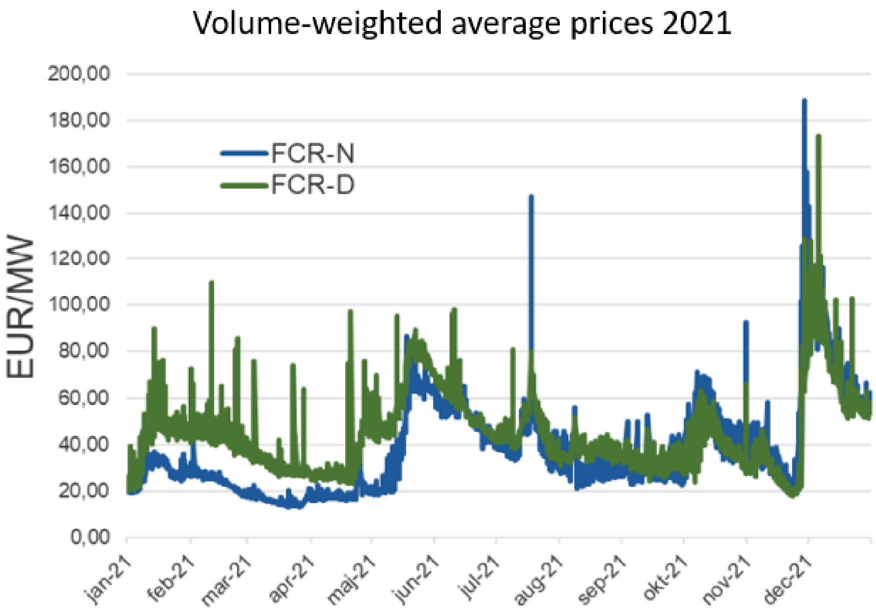

Figure 7. Volume weighted average prices of FCR-D and FCR-N during 2021. Translated from Svenska kraftnät (2022f).

5.3.1.2. FFR

Compared to the costs for FCR-D and FCR-N, the costs for FFR are substantially smaller. FFR was introduced on the balance market in 2020. In 2020, the cost for FFR was 14 million SEK, which increased to 80 million SEK in 2021 (Svenska kraftnät, 2022e). In 2022 the cost decreased to 59 million SEK (Svenska kraftnät, 2023g). The reason for the big increase between 2020 and 2021 was the fact that both Ringhals 3 and 4, two of Sweden's 6 nuclear reactors (Strålsäkerhetsmyndigheten, n.d), were out of operation at the same time during August 2021 (Svenska kraftnät, 2022e). This, in combination with the limited size of the market and few possible suppliers, lead to very high prices, and hence, increased costs. In 2022, the need for FFR was lower compared to the previous year, much due to more synchronised nuclear plant revisions (Svenska kraftnät, 2023g). As a result, smaller volumes of FFR were bought in 2022, and hence, the costs were lower.

5.3.2. Competition on the market

In the year 2021, Svenska kraftnät started a project with the goal to increase the number of suppliers of support services (Svenska kraftnät, 2022e). In the shift towards renewable energy sources, more support services are needed to balance the system and Svenska kraftnät has identified the need to increase the competition between suppliers of support services. To achieve this, a number of actions were taken. Svenska kraftnät has both tried to make the process of becoming a supplier easier, as well as increase the transparency of the market. They have also tried to spread information in order to answer any questions that both potential and existing suppliers might have about the market. However, in 2021, the increase in the number of suppliers was not as large as Svenska kraftnät would have wished. They noticed that many actors still were waiting for the coming separation of the roles between BSPs and BRPs before entering the market.

One step towards increasing the number of suppliers of FCR was to change the pricing mechanism. The first of January 2022, the requirement of making cost-based bids on the balance market was dropped (Svenska kraftnät, 2022e). The reason for this was that Svenska kraftnät identified this as a barrier of entry on the market, since the cost-based pricing requirement created insecurity among the suppliers about how they were allowed to price FCR. This made the suppliers hesitant to enter the market. The next step is a switch to marginal pricing by 2024, something Svenska kraftnät hopes will further increase the incentives for new suppliers to enter the market.

In 2022, results of Svenska kraftnät's efforts to increase the number of suppliers of support services started to show (Svenska kraftnät, 2023g). Compared to 2021, the number of pre-qualifications was tripled, and in comparison to 2020 they increased tenfold. The increase of pre-qualifications per year and type of support service can be seen in the graph below (figure 8). However, according to Svenska kraftnät, the number of suppliers still needs to further increase to meet the increased demand for support services.

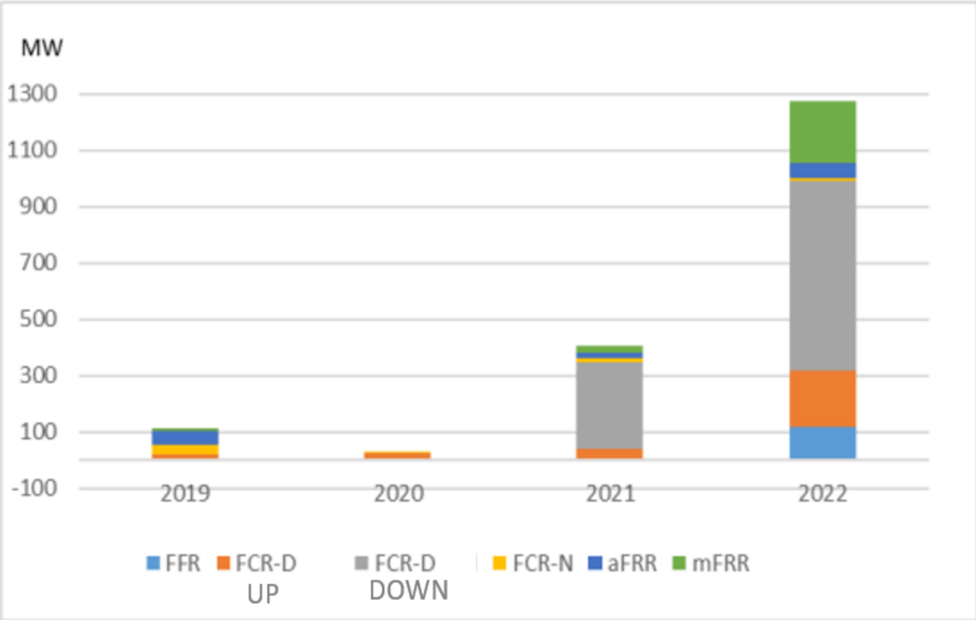

Figure 8. Increase in pre-qualified volume of support services per year (Svenska kraftnät, 2023g).

5.3.3. Forecasts about the future market

Svenska kraftnät has made several forecasts about the costs for frequency reserves in the coming years (Svenska kraftnät 2021i; Svenska kraftnät 2021h). The forecasts expect the costs for support services to continuously increase, until the year 2024, where a peak is reached, and after that, the cost decreases.

Figure 9. Forecast of costs for support services. Translated from Svenska kraftnät (2021i).

Svenska kraftnät has also made forecasts of the estimated maximum volume of FCR-D and FFR, compared to what was actually bought, which can be seen in the graph below (figure 10). According to Svenska kraftnät (2022g), the reason for the difference between the forecast and the actual bought volume, is the lack of available FFR resources and suppliers. The reason for the lesser difference between forecast and actual outcome in FCR-D upwards is that the market is more established. As mentioned before, FCR-D downwards is a new product from 2022 and the bought volume is planned to increase gradually. As can be seen in the graph, the volume of FFR is prognosed to increase the next couple of years, while the need for upwards and downwards FCR-D is forecasted to remain around the same level once downwards FCR-D has reached the planned maximum volume. This is reasonable, given that the need for FCR-D only should change if the dimensioned error in the system changes.

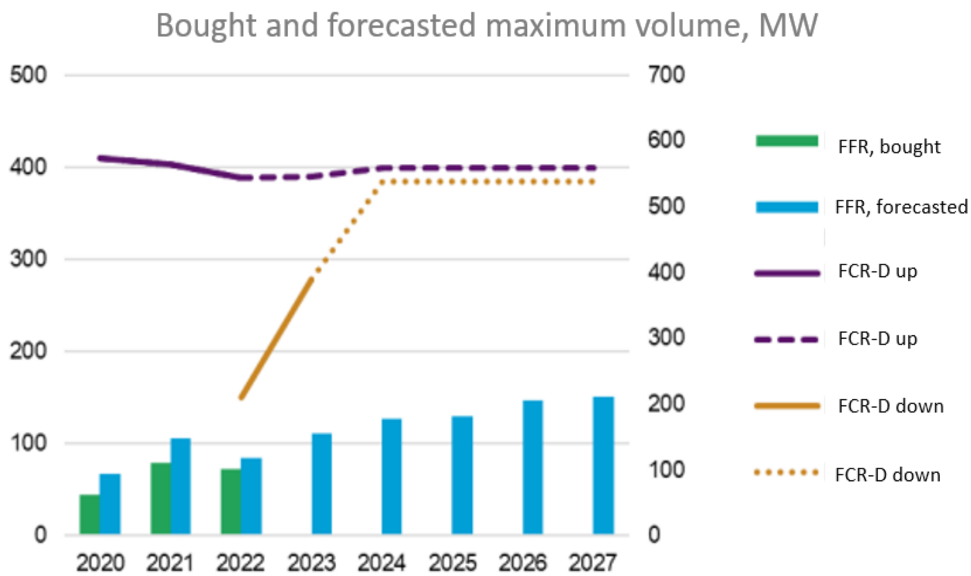

Figure 10. Bought and forecasted maximum volume of FFR and FCR-D. Note that FCR-D is measured by the right axis of the chart. Translated from Svenska kraftnät (2022g).

5.4 Choosing the user cases

In order to answer the research questions, three case studies were conducted to understand the market, and find possibilities and obstacles for heavy vehicles and sites with energy reserves to take part in the frequency regulation market. Furthermore, looking at different cases can broaden the understanding of what roles and actors are relevant for frequency regulation. In order to find relevant cases, a number of different potential cases were briefly explored based on the following relevance criterias:

- Predictability
- The time that the energy reserve is connected to the grid
- The size of the energy storage
- The accumulated capacity
- The maturity of the technology

This was done to get an overview of potential relevant actors and sites, and to exclude ones that are less relevant. A more thorough investigation of these criterias was then done on the chosen cases, which will be described later in this report.

Below is the first exploration of cases. These were chosen from discussions with interviewee 1, and from statistics and other secondary data. There were also some cases that were discussed but found less relevant due to obvious low potential or due to the fact that they lie outside the limitations of the thesis, and those were therefore excluded from the first exploration. Some examples of such are heavy industry, agriculture, real estate, and other public sites with backup power in the form of big batteries. If a case was found to have low potential on one or more of the aspects, it was in some cases excluded without going onto further investigate the other aspects. Moreover, some aspects were difficult to get a sense of from literature, but if the case in question has good potential in other aspects it could still be chosen. Then this aspect was further explored during the main data collection phase. Below is the first selection of explored cases.

5.4.1 Buses

In this case, focus will be on buses in public transport, but most of what is found can be applied to other buses as well. Buses in public transport follow a fixed timetable, making it very easy to predict exactly when the buses will be out on the roads and when they will be back at the terminal, charging (Interviewee 1; Interviewee 3). This means that buses have good predictability. Many of the buses in public transport are not used during the night, which means that there are several hours during the night during which they can be connected to the power grid (Interviewee 1; Interviewee 3). The batteries in electric buses are quite big, and since a regular bus operator operates a number of buses, the connected energy reserve is found to be a sufficient size (Interviewee 1; Interviewee 3). This makes it interesting as a case. Moreover, electrification of buses has come quite far compared to other heavy vehicles. According to data from Trafikanalys (2023) gathered and put together in table 1 below, 7,5% of all buses in Sweden are electric buses.

Case	Number of electric vehicles	Total number of vehicles	% of electric vehicles within segment, year 2022
Buses	1062	14239	7,5%

Table 1. Statistics over electrification of buses in Sweden (Trafikanalys, 2023).

5.4.2 Trucks

Trucks of different sizes are used for a variety of purposes. Depending on the context, routes and timetables for trucks can vary in predictability (Interviewee 1). However, in many cases, the timetable and whereabouts of a truck fleet can be predictable, such as for shorter distributors with recurring routes and driving patterns. According to interviewee 1 and interviewee 3, many haulage companies and distributors have overnight depots where the electric trucks will charge during the night, and thus be connected to the power grid. This makes for a sufficient time and hence a relevant case. Heavy trucks can be charged both at private depots, public and semi-public charging points (Power Circle, 2021). Semi-public charging points refers to, for example, ports and logistics hubs and public charging points can be found at the side of the road like regular gas stations. Power Circle presents numbers from BIL Sweden, showing that depots will stand for the majority of the charging of heavy trucks, approximately around 80%. This will mostly be done during night-time. Moreover, according to Power Circle, for many of the regular distribution routes, additional charging during the day may not be necessary. This does not apply for longer transports, where trucks might need to charge at charging points along the way.

Similar to buses, the battery in the truck itself is large, and if a number of trucks are connected to the power grid at a charging station, then the total size of energy storage makes for an interesting case (Interviewee 3). The electrification of trucks has not come as far as for buses, see table 2 compared to table 1, but is likely to increase in the coming years (Interviewee 1).

Case	Number of electric vehicles	Total number of vehicles	% of electric vehicles within segment, year 2022
Heavy trucks	119	86060	0,1%

Table 2. Statistics over electrification of trucks in Sweden (Trafikanalys, 2023).

5.4.3 Personal cars

Personal cars as a group can be considered rather predictable, with similar usage patterns. Many cars are charged at the owner's place at night, and thus connected to the power grid (Energimyndigheten, 2021a). During the day, many personal cars are used with similar driving patterns. According to Energimyndigheten, personal cars are in general parked 23 hours per day, often at the home of the owner, making this time appropriate for charging. Company cars are used very similarly, but instead of being parked at the owner’s home, they are parked at a parking lot belonging to the company. Since an average car is parked 23 hours per day, this makes for good potential regarding the time that the energy reserve is connected to the power grid.

Even though the total sum of batteries in electric cars adds up to a big energy reserve, the size of energy storage per customer is rather small, making the case less interesting based on the criteria of this thesis. Since a majority of charging is done at the car owner’s home (Energimyndigheten, 2021a), every single customer has a small potential in the size of energy storage.

Personal cars is one of the cases that has come furthest in the electrification, with a relatively high percentage of electric vehicles, see table 3. However, the potential per customer is quite low which makes the case less relevant in this study (Interviewee 1). Personal cars are therefore not an interesting case for this thesis.

Case	Number of electric vehicles	Total number of vehicles	% of electric vehicles within segment, year 2022
Cars	610716	4980543	12.3%

Table 3. Statistics over electrification of personal cars in Sweden (Tafikanalys, 2023).

5.4.4 Logistics hub

Another potential case is logistics hubs. One kind of heavily trafficked logistics hub is ports. Since the ports are a junction for transport vehicles, there will be a great need for green energy there, as the transport sector becomes increasingly electrified, including boats. Moreover, Lind et al. (2020, updated 2023) describe that over 95% of Sweden's trade of goods pass through ports, and the authors therefore emphasise that ports will have a significant role in the shift towards climate friendly transport. According to Lind (2021), ports have the potential to become a charging hub offering locally produced renewable energy, as well as having energy reserves. Ports can therefore be considered having the important characteristics of a logistics hub and will henceforward be the representative for logistics hubs.

Maritime vessels carrying either passengers or goods, as well as land-borne traffic that transports the goods from and to the port, can be considered to follow some kind of timetable that can be known in advance. Passenger boats having a fixed timetable are very predictable whereas ships transporting goods can be affected by delays and have more unpredictable patterns.

In a report ordered by the Swedish government, Trafikanalys (2022) investigated the market for electrification of harbours and boats. Trafikanalys came to the conclusion that there is a big potential for electrification of maritime traffic, and that the potential for electric boats driven by batteries as of now, mainly lies within passenger traffic. This kind of traffic usually travels relatively short distances, with a consistent route between the same harbours, which suits well with the properties of battery-driven boats. One important factor for the increased electrification of maritime traffic is the availability of the necessary infrastructure. There needs to be availability of both electricity for charging and for shore side electricity, which enables electrical power onboard also when the battery is charging. Compared to other European countries, Sweden lies ahead when it comes to the number of harbours that offer some kind of shore side electricity (9 harbours), even though the usage percentage still is low.

As of now Sweden is ranked number 6 in the count of countries with the most electric maritime vessels, with 17 vessels in use and 6 more ordered, which equals a growth of 35%. Ranked number 1 in the world is Norway with 202 vessels in use and 43 ordered (growth of 21%). Finland and Denmark are ranked 8th and 12th. Even though electrification of ports is still in a very early maturity state, there is still potential to be found from the gathering of various vehicles that to some extent has, or will, become electric.

Both electric boats and electric trucks and other port vehicles can be considered to be in possession of large batteries, and thus, a collection of such will together have a significant size.

5.4.5 Solar parks

This case will represent sites that in some way produce solar power, either as their main activity or as a side activity for either selling or own usage. Solar power is one of the renewable energy forms that is easy to produce at one's own site. Thus, producing solar power is easy to combine with other activities, at sites where energy production is desired. According to interviewee 2 (2023), Business Developer, Technical Design of Photovoltaic Power Station, E.ON, the energy received from a solar park can be predicted with some accuracy over a year, by month. It is more difficult to predict per hour, but there are some websites for historical data that can be used to make predictions.

Solar parks can have a battery connected to the power plant, to store energy. According to interviewee 3, solar parks have a great potential in connecting to a battery that then can be used as a frequency reserve. These batteries are suitable for both upwards and downwards FCR-D, as well as FFR. Interviewee 3 further means that the potential of both up- and downwards FCR-D comes from the ability to keep such a battery at around 50% charging level, compared to a battery that needs to be fully charged for usage, for example a bus battery that otherwise might not make its full route.

If the battery is solely used as a frequency reserve, then it can be an available resource as long as it is sufficiently charged (Interviewee 3). This makes the availability rather predictable, especially if the battery can be charged from the power grid as well, when the weather is unfavourable. If it is used for short-cycled regulation, then the battery has time to recharge in between so that it can be kept at a desired level of charging, and therefore equipped to serve as a frequency reserve. One limitation, according to interviewee 2, is that if a solar park has an agreement regarding how much energy it can provide the power grid, then it is not possible to regulate in a manner so that more energy is supplied to the power grid, exceeding this limit.

In Sweden, there were 59 solar parks with a capacity of >1000 kW, and 12 093 solar parks with the capacity of 20 kW–1000 kW connected to the power grid, the year of 2021 (Energimyndigheten, 2022d). One of these bigger parks, Alight in Linköping, a 12 MW solar park has installed 2 MWh batteries, which makes this the largest solar park in Sweden with batteries as energy reserves (Wennerberg, 2022). The purpose of the battery is to act as a frequency reserve. Wennerberg further describes that the battery also can be used to store solar energy and sell it when it is most profitable, and also to provide electricity when the sun is not shining. Before the year of 2025, Alight together with Varberg Energi aim to install energy reserves with the capacity of 25 MW in southern Sweden, which should be used for flexibility services and power grid related synergies (Alight, 2022). Therefore, it can be seen that the technology is available, and the market has started to develop.

5.4.6 Mines

There are currently 12 mines in operation in Sweden (Sveriges geologiska undersökning, 2022). They are managed by six different companies, where Boliden Mineral AB, one of the biggest mining companies in Sweden, manages five of them. The last couple of years Boliden has taken several steps towards electrification of the heavy mining industry (Boliden, n.d). In Kristinebergsgruvan (one of Boliden's mines in Sweden) a new "electric-trolley-assisted" truck transport system has been implemented, which replaced diesel-driven vehicles and machines (Energimyndigheten, 2021b). This initiative was supported by the Swedish energy agency with 66,8 million SEK as a part of the program "Industriklivet", which aims to support industrial companies trying to reduce their emissions of greenhouse gases.

Boliden has also started the process of electrification in two other mines, Aitik and Kevitsa (Boliden, n.d). In the year 2018, a 700 metre long electric-trolley track was built, together with conversion of four mining trucks from diesel to electricity. This was a pilot project that generated positive results both regarding efficiency and decreased need of maintenance. Now, an additional three kilometres long electric-trolley track will be built, together with conversion of 10 further trucks to electric operation. This will reduce greenhouse gas emissions over the lifespan of the mine by 15%. In Boliden's mine in Kevitsa, a similar project will be implemented, where a 1.8 kilometres long electric-trolley track will be built, together with the conversion of 13 trucks to electricity.

LKAB (Luossavaara-Kiirunavaara Aktiebolag) is the owner of three of 12 operating mines in Sweden (Sveriges geologiska undersökning, 2022). They have started the process towards fossil free mining by replacing trucks and other vehicles run by fossil fuels with electrical vehicles (LKAB, 2021). Their goal is that iron ore from the mine Malmbergsgruvan is to be fossil free by 2026. In December 2022, the first electric heavy tipper truck was deployed at the mine, and during 2023 several more electric trucks are to be expected (LKAB, 2022).

In the Kaunisvaara mine in Pajala, the owner company Kaunis Iron AB has started a collaboration with energy producer Vattenfall, in order to reduce the use of fossil fuels in the operations of the mine (Vattenfall, 2021). Together they aim to develop solutions for electrification of transports both within the mine, but also in the area surrounding the mine and potentially also for the transport between the mining area and the transhipment terminal.

It can be seen that mines have started to become electrified, and thus, the technology and market has started to develop. The size of the individual energy storages might be sufficient, but the total number of potential actors within this segment is limited due to the fixed number of mines. Therefore, even if there is some electrification, and hence some potential in the case, the accumulated capacity of mines is considered by the evaluation aspects of this thesis to be too small for further investigation.

5.4.7 Summary and choice of cases

In the process above, six different cases have been investigated based on their potential. The factors that have been used to assess the potential are size of the energy storage, accumulated size of the potential and realised market, predictability, time when the energy reserve is connected and available and maturity of the market and technology. Below is a summarised assessment, where, for each case, the factors have been given different colours based on their potential. Red means that the potential is low, making the case uninteresting for this thesis. Yellow means either that the potential is medium or that it is unknown. Finally, green means that the factor has big potential for the case in question, based on the findings.

	Size of energy storage	Accumul-ated size of potential market	Accumul-ated size of realised market	Predictability	Time	Maturity of technology
Buses						
Trucks						
Logistics hub						
Solar parks						
Personal cars						
Mines						

Table 4. Assessment of the potential of the different cases.

As can be seen in table 4, only two of the above cases have red variables. Mines have a low total accumulated size of market, making the potential and thus relevance low. Personal cars have a large total accumulated size of energy storage, but the size of every battery is small, making personal cars less interesting for this specific thesis. Even though a case might be excluded from this thesis, it can have big potential in another context. Being assessed as red is therefore not equivalent with having no potential in any context, but rather not having the potential that is searched for in this thesis.

All the other cases are assessed as either only green on all variables, or green and yellow on all. Buses and trucks that stand in overnight depots have similar characteristics and both good potentials. Therefore, these are joined together into the first case called *overnight depot*. Logistics hub is assessed as both green and yellow, since several factors are unknown but might have good potential, making the case interesting. The unknown factors will be further investigated in a deeper examination of the case. Case number two will therefore be *logistics hub* and will as previously mentioned be characterised by ports in this thesis. The third case will be *solar parks*, which has been assessed as green on all factors.

5.5 Introduction to the chosen cases

As mentioned above, the three cases that will be investigated are *overnight depot, logistics hub* and *solar parks.* Below follows a more extensive examination of the three chosen cases. The examination and analysis are based on interviews and correspondence with relevant actors and experts within each case and secondary data. For each case the findings from the investigation will be presented as well as an analysis of technology maturity, stakeholders and value networks based on the theoretical framework presented above.

As there is some similarity between case one and the two following in regard to, for example, the relevant actors and the technology, many of the findings in case one will be applicable in the other cases as well.

5.6 Case 1 Overnight depot

5.6.1 Characteristics of overnight depots

There are many different kinds of transport companies and haulage contractors that provide logistics and transport services. There are both small haulage contractors that operate more stand-alone, and also larger transport companies that coordinate and aggregate the services of many smaller actors. In this thesis, three different actors have been interviewed. The first two interviewed companies are aggregators, coordinating many actors under one company, meanwhile the third one is a bit smaller and owns and operates most of its trucks themselves. Below is a more thorough description of the characteristics of the different interviewed companies.

5.6.1.1 Transport company 1

Interviewee 6 (2023) is a CEO at the large transport company in Malmö, with 95 different smaller haulage partners, operating in construction-, return-, goods- and warehouse logistics with a focus on sustainability and innovation. The company itself does not own and operate the trucks, but rather do the logistics planning and coordination of the 95 partners, who are responsible for maintaining the truck fleet and operating the trucks. In total, the company has around 450 trucks in service, and their distribution area is in southern Sweden, covering Skåne, Blekinge and Halland. The company also has longer delivery routes going to, for example, Stockholm and Borås. Even if the company itself does not own the trucks and is therefore not responsible for the investment in new electric trucks, they take part in the electrification and support their partners in their transition. Today, the company has three electric trucks in their operations, and one more on the way. According to interviewee 6, they want to see how the projects with the current electric trucks turn out, so that, if necessary, changes can be made in future electrification projects. Since this is a rather new field, it is not always clear how the operation of the electric trucks should be done, and therefore it is of interest to learn from previous projects and develop it further for the next one.

5.6.1.2 Transport company 2

Interviewee 8 (2023) is Business Area Manager for logistics and environment at a logistics company in Norrköping. The company manages about 300 heavy trucks, and 150 light trucks of various sorts. The company also has two subsidiaries that own a few of the trucks in operation, but the rest is owned by partner haulage contractors. Interviewee 8 describes the relation as a sort of franchise where the company markets their partners and provides them with different services and functions such as environmental certifications, takes the credit risk, and can coordinate different trucks and teams. The company has started to electrify their transports, and they have one heavy electric truck in operation, a couple of light trucks, and more on the way. They are planning to install a new charging station of 400 kWh and two chargers.

The initiative to electrify has been significantly driven by the company, but the company itself cannot support the individual haulage contractors' investments. Instead, they have had dialogues with the partners that are interested in electrification and willing and able to take on such an investment and the risk that comes with it. Even though the company cannot contribute with financial means, they can still help with the electrification in other ways.

5.6.1.3 Transport company 3

Interviewee 10 (2023) is a Key Account Manager at a haulage contractor in southern Skåne. The company has about 100 trucks in operation, out of which they own the majority, and has now electrified 9% of their vehicle fleet. The company has developed its own fleet and has now learnt a lot about how the batteries in electric trucks work, and today, their electric trucks operate almost all hours of the day, charging 30 minutes when it is loaded and unloaded. However, they have one truck operating at their home base that is charged in an overnight depot. The company has its own charging infrastructure on its site, and some infrastructure at customers' sites in different collaborations.

5.6.1.4 Bus operator 1

Interviewee 18 (2023) is the fleet director of Keolis Sweden, one of Sweden's biggest operators of buses for public transport. They own approximately 1600 buses in Sweden and started their electrification journey in 2014. When asked about Keolis view on the investment decision of investing in electrified buses, interviewee 18 answers that since the war in Ukraine, electric buses are the cheapest alternative if the utilisation is high enough, and that 80-90% of their trafficked routes would be cheapest fuelled with electricity.

The majority of the charging is done at their sites in the depot (approximately 95%), and in very challenging traffic situations the buses are charged and the end station (approximately 5%). The time spent in depot varies depending on which route the buses are driving, but according to interviewee 18, generally a big share of the buses is standing in depot between 23.00-05.00.

5.6.1.5 Ica

In order to understand the case setting from a customer of distribution services point of view, an interview was conducted with a strategic logistics developer- transport at ICA (Interviewee 15, 2023). Interviewee 15 works within the operational part of Ica that handles purchasing, sourcing and distribution of goods. Ica has begun electrifying their transports and has, at the moment, five electric trucks. The first truck did city-bound distribution in Stockholm, which was shorter and lighter transports. Now, the deliveries with electric trucks have increased both in length and weight load. For example, one of their electric trucks drives between Helsingborg and Gothenburg two times per day. Otherwise, most of the trucks are in operation between 06 in the morning and 18-20 in the evening.

90 to 95% of the distribution is outsourced to external parties, and 5% are made by their own haulage contractor. Normally, the external haulages own and operate the trucks, but with the electric trucks it is quite different. Since the investment costs were high, Ica owns the electric trucks instead of the haulages. Ica then leases the trucks to the haulages. However, it is not certain that this arrangement will continue with further investments.

Regarding electrification, Ica has a collaboration with Volvo, to obtain mutual benefits on strategic areas, and strengthen both parties (Interviewee 15). Their deliveries follow a strict schedule, with recurring routes every week. Ica themselves has taken on a defensive approach to investing in charging infrastructure and does today rely on supply from public charging. In the future it is likely that the trucks will be charged during loading and unloading of goods. For a small truck, loading and unloading takes around 30 minutes, and for the largest trucks, it can take up to 1,5 hours.

5.6.2. Current state of market

The transport industry is just beginning its electrification, and the three logistics companies described above are all in the forefront of it, with a couple of electric trucks each, and more on the way. Electrification is not always a rapid process, and it can take about one year from an order of a truck till its arrival (Interviewee 8).

The charging patterns of the different trucks varies both between the company and also between different trucks within the same company. There are both trucks that are in operation almost all hours of the day, those that stand in an overnight depot for several hours every night, and those that combine these. Some of the trucks are only charged at the home site during the night, some are fast charged 30 min every time they are loaded and unloaded, and some trucks need to be charged along its routes. Transport company 2 has electric trucks that are normally charged at the overnight depot from 16-18 in the afternoon to 05-06 in the morning after. Transport company 3's trucks, on the other hand, normally run all hours of the day, and are charged in periods of 30 minutes. Moreover, the driving patterns for the fossil fuelled share of the truck fleet can vary between different companies. Some of the fossil fuelled trucks are in operation all hours, and some are in the depot from early evening to early morning. The majority of bus operator 1's buses are driven according to their timetables, and stand in overnight depots during the night (Interviewee 18). Their driving patterns are highly predictable, apart from unexpected events, and only a small share on their buses charges along the route in locations apart from their depots.

According to interviewee 10 and interviewee 11 (2023) eMobility Manager, Veho Import, there is a span of charging rate that the batteries ideally should be kept within, which is 20- to 80% charged. When the battery passes 80%, the effect, and thus the pace of charge is lowered. Moreover, there is a buffer margin which means that when the battery is discharged and at 0%, it is not actually fully discharged. This is to avoid unnecessary wear of the battery.

From interview 6, 8, and 10, it was understood that the investment in electric trucks is considered very high and a challenge for many actors, not least for smaller actors with less capital. Also, the profit margins for haulage contractors are small as it is of today, making it challenging for them to fit the larger investment cost into their budgets (Interviewee 6; interviewee 11) This means, according to interviewee 6, that other actors need to be willing to take the extra cost of the transport, such as stores or the end customer. The extra cost has led to increased utilisation of the electric vehicles for some of the actors, driving them all hours of the day. Moreover, the industry has seen an increase in leasing trucks, especially electric trucks (Interviewee 9; Interviewee 11). Also, leasing times has grown shorter, and are often around 3 years instead of previous 5 or 6 years (Interviewee 11).

For electric buses, the investment cost might not be as challenging as it is for electric trucks. According to interviewee 18, electric buses are the cheapest alternative as long as the utilisation is high. Also, as described in 4.7.1.1, there is the electric bus bonus paid by the Swedish government, that can support the investment in electric buses. Today, there is not a corresponding bonus to be obtained for investments in electric trucks.

It was also made clear from the interviews that the charging price for electricity can be rather high at public charging points, making the operations more costly, and hence, charging at the home depot more profitable. The best public charging price that interviewee 10 has found is 5,95 SEK per kWh. Charging at the home site costs around 2,95 SEK, but fosters a need for chargers, and sufficient capacity from the power grid. This investment can vary both in cost, and complexity (Interviewee 3). There is financial support to receive for establishing charging infrastructure, but it can be challenging to get access to it (Interviewee 11). As described in 4.7.1, financial support can be obtained for establishing charging infrastructure. However, it is more difficult to obtain financial support for establishing private charging compared to public. Another factor that can affect the speed of the electrification is the accessibility of surrounding infrastructure. According to interviewee 8, there has been a lack of electrical substations for some time, delaying their new charging infrastructure.

Moreover, there are other current challenges with public charging stations that raise uncertainties for operators of electric vehicles. Firstly, the vehicles often have strict time schedules and if there is a queue at the charging station, they might miss their deadlines or not be able to make the full route (Interviewee 8). Also, the access to public charging is uncertain, and it was found that charging infrastructure is not yet widespread enough (Interviewee 6; Interviewee 10). This leads to challenges in making all routes electrified. The optimal driving pattern to reach would be to drive 4,5 hours and then charge for 30 minutes meanwhile the truck driver takes a break (Interviewee 9 (Director Business Development, Volvo), 2023). Interviewee 9 means that this is a tipping point in which the technical aspects of driving an electric truck meets the allowed driving patterns for the truck driver.

One thing that can restrict the ability to charge a large vehicle fleet at depots today is the maximum power output that is possible at the site (Interviewee 3). This can, for example, be caused by limited infrastructure with too few or limited cables in the ground. If this is the case, then electrification will require buffer batteries or other energy reserves that can be used, in addition to charging from the power grid, to meet the demand for electricity (Interviewee 3). Also, if a large number of heavy vehicles are charged at the same time and at the same place, such as over the night at the depot, then a limitation in capacity from the power grid might be reached. Then an additional buffer battery can be used (Interviewee 3). During the hours when the battery is not used, there is a great potential for using the battery as a frequency reserve. However, this requires that it is certain that the battery will be available during the hours for which the bid has been accepted on the balance market.

A mapping done by Sahlén et al, (2020) from Sweco Energy AB on the behalf of Energimarknadsinspektionen, shows the lack of capacity from the power grid, and the results of investments done to enhance the situation. According to the report, lack of capacity is often mentioned as an obstacle to environmental sustainability and growth. Lack of capacity is described in the report as the power grid’s inability to deliver the requested amount. Electrification increases the need for electricity in certain areas and thus, puts new demands on the capacity of the power grid (Interviewee 3). This can in some areas be challenging, resulting in a lack of electricity. The assessment is shown in table 5, which is a remake and translation of a table presented in Sweco’s report. The colour red means that the demand cannot be met in the area at present or is expected to not be able to meet the demand at a certain year. Yellow symbolises that it is not certain that the need will not be met but that there are requests that might turn into real “bookings”, resulting in lacking capacity. Green represents areas that are assessed to be able to meet the requested capacity. Table 5 only shows capacity for output and not for input.

Area	Situation 2020	Situation 2025	Situation 2030
Stockholm			
Uppsala			
Malmö			
Västerås			
Luleå			
Skellefteå			
Östersund			
Gotland			
Västkusten			
Södermanland/ Östergötland			

Table 5. Image of translated results of an assessment done by Sweco, showing the output capacity from the power grid in different parts of Sweden. (Sahlén et al., 2020)

Sahlén et al. (2020) further describes that electrification of the transport sector will have an impact on the total use and need for electricity over the coming ten years. Where and when the electric vehicles will be charged will play a significant role in the sift of demand for capacity. According to Sahlén et al, personal cars are expected to stand for the biggest part of the increase in demand. However, according to Interviewee 3, a charging station for heavy electric vehicles will in one place create a huge demand, making these charging hubs a contributor to lack of capacity.

5.6.3 Possibility for V2G

As described in the background, V2G is the concept of feeding back energy from a vehicle to the power grid. V2G would technically be possible today, with some minor modifications on the current technical solutions, according to interviewee 9, Director of Business Development at Volvo Trucks, and interviewee 11, eMobility Manager at Veho/Mercedes in Sweden. However, V2G is a rather new and unexplored area, and more research and tests would need to be conducted before this feature can be seen in electric trucks. Also, there are several more pressing areas to look into, such as range and battery lifespan (Interviewee 11). Interviewee 11 distinguishes between things that you need to have, and things that are nice to have. At present, V2G is considered a “nice to have”, which makes it a less prioritised matter. Interviewee 11 sees a possibility of V2G being a part of a future holistic energy system, where heavy trucks might act as a power bank, and can be used for powering other devices.

If circumstances were to change, and technology develop, and allow V2G for batteries in heavy vehicles, it would open up possibilities for using vehicle batteries as frequency reserves (Interviewee 1).

According to interviewee 10, their electric trucks are today in service almost all hours of the day and night to get the calculations to add up. Also, interviewee 6 describes that the utilisation rate at this stage must be higher for an electric truck, since the investment is bigger than for a regular diesel truck.

However, there are also electric trucks in service today that are parked at an overnight depot around 12-14 hours over the night (Interviewee 8). This means that some trucks do have hours to spare, with available capacity, during the night. As discovered in interview 18, this also applies to buses since a large part of their fleet stand in overnight depots between 23 and 05. As long as the vehicles are sufficiently charged for the next day’s utilisation, there is a potential for using the extra capacity as frequency reserves via V2G.

5.6.4 Analysis of maturity of technology

As has been described earlier, FFR is a rather new form of frequency regulation, from 2020. Additionally, downwards FCR-D is even more novel, since it was introduced in 2022. Therefore, these markets are quite new. As a result of energy storage being one of the most favourable FFR reserves, it is the second largest source of FFR (Svenska kraftnät, 2023d). Regarding FCR-D, energy storages still provide a very small share of the total supply. The very majority of FCR-D today is done by the big energy suppliers using water power, and the share of FCR-D provided with energy reserves is currently less than 1% of the supply. Potential sharpened requirements on the suppliers of FCR-D might however change the distribution between different sources.

Today there are both electric trucks and buses on the market with the dimensions and capacity for local and regional distances. Regarding the longest and heaviest transports, there are no models yet that quite fulfil the requirements. According to interviewee 9 and interviewee 11, there are new truck models on the way and vehicle manufacturers are developing electric trucks for longer distances and heavier loads. According to interviewee 11, the technology for batteries is also developing at a high pace. An improvement of battery quality and reach will help in the electrification of heavy vehicles, and new kinds of batteries will hopefully be developed in the near future.

It was seen in 5.4.2 that the share of heavy electric trucks is less than 2.5%, out of all registered heavy trucks. This would, according to the diffusion of innovation theory, place the technology in an innovator phase. According to the theory, it means that only actors that are willing to take risks, and that are passionate about new technology and development have taken the step to start electrifying their vehicle fleet. This seems somewhat in line with what was found from the interviews. The actors that have chosen to invest in electrification want to be, and are, at the forefront of the development, and are willing to take risks to see results. It was found that these actors are taking part in pilot projects, testing new technology that at present is unknown to most.

In the year 2022, 7,5% of all registered buses were electric buses. This places electric buses in the early adopter segment. This segment sets, according to theory, the tone for the future adoption for the following segments. This means that if the use of electric buses runs smoothly, it is likely that the rest of the segments will follow and adopt the technology as well. In theory, Moore (2014) presents what he refers to as the chasm, which is a gap between early adopters and early majority. This chasm is not always so easy to cross, according to Moore. But in the case of buses, electrification seems to be a natural step that most actors will have to take eventually, due to economic and regulatory reasons. One reason for the development not having gone further is the fact that not all old fossil driven vehicles have yet reached their end of life and will therefore be driven until they are worn out. Also, many buses and some trucks are already driven on other renewable fuels and are therefore already considered renewable.

As the technology matures and more customers adopt electric heavy vehicles, the technology moves to the right on the S-curve. This places the technology in the steeper part of the curve where the development is fast. It is likely that, as the technology matures and more customers buy the product, the cost of it decreases. This is in line with what the interviewees believe and hope for. A decreased investment cost would facilitate for haulage contractors to invest in electric vehicles, which today can be a challenge with the high cost and low margins.

As has been found in this part of the analysis, measures for electrification are being taken throughout the transport industry. There is a quite wide spread between how far different actors and technologies have reached in their electrification, but most are advancing and can be expected to do so onwards.

5.6.5 Stakeholder analysis

In the context of the case for overnight depot, many stakeholders can be identified. Some of the relevant stakeholders that have been identified from interviews and literature are haulage contractors, logistics companies, bus operators, the customers of these actors, owners of charging infrastructure, owners of the local power grid, suppliers of material for charging infrastructure, vehicle manufacturer, policy makers and Svenska kraftnät. As is described in theory by Johnson et al. (2008), these stakeholders can be divided into economic-, socio/political- and technological stakeholders based on the nature of their influence. Depending on what actor’s point of view is taken, the division can vary. A haulage contractor can be considered an economic stakeholder in the eyes of both their customers and Svenska kraftnät. The Swedish government is a socio/political stakeholder enforcing regulations and policies that affect the other actors. Moreover, different vehicle manufacturers can be considered both economic stakeholders, supplying vehicles, and technological stakeholders, since they are the ones developing the new technology. Also, suppliers of batteries, and the development of their technologies will affect both the vehicle manufacturers and the rest of the actors that are affected by the technological development.

To understand the roles of the stakeholders, they can then be mapped into a power/interest matrix, based on their level of interest and their power. Depending on which actor's point of view is taken, the mapping can look different. As a haulage contractor, customers can be considered having high power, and either low level of interest, or high, depending on the extent of their involvement. For example, when looking at electrification cooperations between transport companies and their customers, it can be seen that the interests and influence of both parties are high, and therefore, they become key players for one another.

It can be seen in the context of electrification that more actors need to work together, thus increasing their level of interest in each other's strategies. Also, in the case of collaborations, they can be considered sharing a strategy. It was also found that customers, such as Ica, and logistics companies work together with vehicle manufacturers in partnerships to develop their electric transport. This means that their relationship shifts towards high on both scales, making them key players for each other. If they do not collaborate, but the logistics company has a leasing contract at a manufacturer, then they could be considered category A.

If a logistics company starts to deliver support services to Svenska kraftnät, then the nature of their relationship shifts. Before, their relationship could be considered to be of a minimal effort kind, but as they start interacting more, delivering services both ways, then they move up on both the interest and power scale. Every logistics company itself might be too small to be considered a key player in the eyes of Svenska kraftnät, but with potentially sharpened requirements on delivery time of FCR-D, then batteries as a source of frequency regulation, and thus actors possessing these resources, can become key players. Together they then share a common interest of keeping the power grid stable. For logistics companies, FCR-D and FFR could be potential significant sources of revenue, meanwhile increased electrification also makes them more dependent on the reliability of the power grid, making Svenska kraftnät a key player for them as well.

Regarding owners of charging infrastructure, the nature of their relationship to haulage contractors can vary based on the haulage contractors' need for public charging. As was found in the case, some haulage contractors have their own charging infrastructure and are therefore not dependent on access to-, and piece of public charging. However, some actors, such as Ica, have decided to rely on public charging to make their routes. Owners of charging infrastructure could thus be placed in group C, keep satisfied, since they have a big effect on the outcome of Icas strategy, but might have low interest in it. With an increased supply of public charging, then such a relation might shift from C to A, similar to the case of regular gas stations.

Owners of the local power grid can become a key player for sites, when the site wants to build or extend their charging infrastructure. It can be seen in the interviews that the capacity of the grid, and the ability to connect to it, has a huge effect on both the investment cost, and also the time it takes to build new infrastructure.

As can be seen in this case, when the whole industry is starting to electrify, they need to work together, with common strategies to reach their goals. Different stakeholders become increasingly important to each other, having both higher power and interest in each other's strategies and development. This leads to an increased need to take care of relationships with key players in the network. New alliances and collaborations take form and make stakeholders that used to have little interest in-, and power over, a stakeholder become more influential and important.

5.6.6 Value network analysis

Allee (2008) states roles as one of the important elements of the value network. Roles and relationships between stakeholders have already been discussed and mapped out in the power/interest matrix in the previous section, and will therefore not be discussed much further here.

According to Allee's theory of value networks, tangible and intangible value is shared between a group of actors to create social and economic value. This can be seen in the context of case 1 where different actors share resources and values to create more value. This can for example be seen in the case of logistics companies working together with customers to find the best charging solutions, and in the case of actors either sharing the investment risk, or taking the risk for each other, to help the electrification of the vehicle fleet. Another example is customers and logistics companies working together with vehicle manufacturers to create value and exchange knowledge. These are all examples of how electrification brings the value network together, creating more value than every actor can do by themselves.

Regarding the power grid and energy supply, it has been found that electrification and a shift towards renewable energy will create a demand for increased supply of electricity from the power grid, and an increased demand for stabilising services. This opens up new possibilities for sharing value within a value network. Consumers of electricity can both produce their own electricity through solar power, store energy in batteries, interact with the power grid to adjust the electricity consumption, and provide stability services to the grid. This new interaction between electricity consumers and the power grid has increased stakeholders' influence over-, and value to each other, within the network.

One of the deliverables in the context of electrification of heavy vehicles and overnight depots is hours of available capacity for frequency regulation. This is what will actually be sold to Svenska kraftnät. Moreover, other deliverables that are exchanged within the network are the vehicles themselves, the transport services, charging capacity at public or semi-public charging stations, expertise within the field, capacity from the power grid to use for charging the vehicles, and establishment of new infrastructure. Many of these are new in the transport field, as a result of electrification. However, frequency regulation, increased capacity from the power grid and public charging capacity are deliverables that differ a lot compared to older ones within the fossil fuelled transport sector. This is due to their novelty, or the shift in roles regarding who can provide them.

Cooperation and exchange of resources and value in the value network speeds up the electrification, lowers risks for individual actors, and improves total outcomes. According to interviewee 17, most of the relevant trade associations and actors are to some extent involved in networks to drive the electrification forward and create more value together. Since establishing security regarding different concerns in the industry might help increase the pace of development, the exchange of knowledge and experiences is of great importance (Interviewee 17). Throughout this case, a trend towards a closer cooperation to overcome challenges of electrification of the heavy vehicle sector can be seen. Moreover, a more holistic view on energy systems and increased exchange of resources and value between producers, consumers, and maintainers of the powergrid can be seen. This leads to more value for the sector as a whole, and for the individual actors.

5.7 Case 2 Logistics hub

5.7.1 Characteristics of a port as a logistics hub

The logistics hub is generally characterised by large flows of traffic, staying for short times, loading and unloading goods. As a port generally is a location where large amounts of goods are handled and transported, both by land and by sea, this is a location that can be considered a logistics hub, with a large quantity of different operations and coordination. At a port, there are many different actors present and many different activities happening at the same time. Ports are often owned by either a municipality or a private actor and partly operated by them. In addition to the owner of the port, there are shipping companies operating in the port, and logistics companies coming with trucks to the port to load and unload goods. Apart from trucks and ships, there are also a number of working vehicles operating in the hub.

The operation of a port as a logistics hub adds some element of uncertainty, compared to a logistics hub solely focusing on land-based traffic. Interviewee 16 (2023), Technical manager, port of Helsingborg, the ship arrivals are known by day, but not with higher precision, and there are often delays. As the timing and route planning is dependent on when the vessel enters the port, all potential delays of the vessel also affect the planning of further transportation.

Something that was found in all three cases, was that there was generally little to no coordination and optimisation between the different actors operating in the hub. The transport companies make their planning independently of each other, and the hub itself has a very limited responsibility in coordinating to ensure a smooth flow of traffic throughout the day. According to interviewee 7, the head of innovation at the Port of Gothenburg (2023), many drivers and end customers are following approximately the same schedule, having the same delivery times during the day. Therefore, there are certain times during the day where a lot of trucks arrive at the hub at the same time. With an increased share of electric trucks arriving at the port at the same time, it is likely that they might wish to charge at the same time, causing a risk of building of ques and increased waiting times. This can possibly have a negative effect on the flow of the hub, and the logistics companies' time schedule. This implies that a lot of capacity might be needed at the same time, but only during a few hours of the day. At some sites, there might not be enough capacity to cover this need.

In a logistics hub there are many vehicles in the same place at the same time, which also means that with increased electrification, there will be a large sum of batteries in one place. However, as learned in the interviews, (interviewee 7; interviewee 15) the vehicles are not staying in the same place for a long time. After the cargo has been unloaded or loaded, the trucks need to continue on their planned route and leave room for the next truck. This makes the potential for V2G with distribution trucks low in this case.

In the context of potential for support services in general and frequency regulation in particular, the port as a logistics hub possesses an increased potential in the sense that it is a location with many large energy storages in the form of batteries in maritime vessels and other vehicles used in the operation of a port. Although, as of today, there is not a clear way in which this potential can be properly utilised. Below some characteristics of the cases investigated are described.

5.7.1.1 Port 1: Gothenburg

The first interviewee of this case is Interviewee 7, the head of innovation at the Port of Gothenburg. The Port of Gothenburg is the biggest port in Scandinavia and approximately 30% of Sweden's foreign trade passes through the port (Göteborgs hamn, n.d). 70% of all industries in Scandinavia lie within a radius of 500 km from the port and 50% of all container transports in Sweden passes through the port of Gothenburg.

The first step of the increased electrification of the port, according to interviewee 7, is an increased usage of shore side electricity. This will reduce pollution while the vessels stay in port, since the shore side electricity then can be used to provide the electricity needed to run the vessel while in port, instead of the engines. As of now, about 30% of the vessels docking in the Port of Gothenburg use shore side electricity instead of running their engines (a large part of these vessels being Stena Line passenger ferries, frequently docking in the port). One reason for why shore side electricity is not being used by more vessels is that it is, as of now, more expensive to power the vessel through shore side electricity than by combustion of diesel.

In regard to the degree of electrification in other parts of the port, as of now, it is mainly heavy vehicles such as trucks that are being electrified in the area today. Though, this is not the result of any initiative from the port itself, but the decision of the individual haulages and truck owners. Today there is a charging station for electric trucks in the area, which is operated by Circle K upon an initiative from the Port of Gothenburg, where the land for the charging station was offered for free in exchange for the operation and building of the charging station.

The maritime vessels are further behind in regards of electrification, and according to interviewee 7, electrification of boats will mainly be relevant for boats travelling short and planned distances within the port, such as service vessels and ferries for passenger traffic.

Even though the electrification of the Port of Gothenburg still is in an early stage, there are good conditions for an increased and expanded electrification in the area. Since the port of Gothenburg is located in a heavily industrialised area, the conditions for accessing additional electrical capacity, in the case of an increased need due to increased electrification, is good. Since a large amount of energy is needed for the industries in the area close by, the electrical infrastructure is well developed, and according to interviewee 7, increased capacity will be quite easily accessed since the infrastructure already is in place.

5.7.1.2 Port 2: Ystad

The second port that was studied in this case is the port of Ystad. The port of Ystad is located in the southernmost part of Sweden, and it is one of Sweden's biggest ports for ferry-traffic (Ystad hamn, 2023). Following Helsingborg and Stockholm, it is Sweden's third biggest port in regard to passenger traffic, with over 2 300 000 passengers travelling from the port in the year 2022 (Sjöfartsverket, 2023). When considering the number of tonnes of goods handled in the port during 2022, the port of Ystad was the 13th biggest port in Sweden.

Interviewee 14 (2023) is the environmental and quality officer at the port of Ystad. As of now the biggest focus in the port of Ystad in regard to electrification has been on enabling shore side electricity for arriving ships and ferries. Currently, all ferry berths except one (where the ferry only lies for 40 minutes at a time, which is a too short time for it to be environmentally beneficial according to interviewee 14) has shore side electricity available. Three ships are connecting to shore side electricity daily, and according to interviewee 14, the port of Ystad is in the forefront in regard to shore side electricity. As of now, there is no electrification of vehicles or maritime vessels in the port. According to interviewee 14, there are plans on building charging infrastructure for electrical vehicles (both for trucks and personal cars) on the site within two years.

The biggest obstacle for the port of Ystad in regard to electrification has been lack of capacity. The lack of capacity means that big investments need to be made in order to further expand the electrification of the port. According to interviewee 14 it is necessary for Svenska kraftnät to increase the capacity for further electrification to be possible.

The port of Ystad is coordinating and driving the work for further electrification, but similar to the port of Gothenburg, they have no actual responsibility of providing enabling infrastructure. In the planning of the logistics, the roll-on, roll-off ferry traffic is following a predetermined timetable, while other ships run on a different schedule. Regarding the logistics of on and off-loading, that is not planned by the port, but by the shipping companies themselves.

5.7.1.3 Port 3: Helsingborg

The third interviewed port is the port of Helsingborg, which is the biggest port in Sweden in regard to the number of passengers per year, with over 5167816 passengers travelling through the port in 2022 (Sjöfartsverket, 2023). The interview was conducted with Interviewee 16 (2023), who is the technical manager of the port of Helsingborg. In regard to goods handled in tonnes, it is the 4th biggest port in Sweden. The port is owned by the municipality of Helsingborg, making the port a governmentally controlled business, something that has implications on rules for sourcing and contracting for example (Helsingborgs hamn, n.d).

As of now, two out of three ferries travelling from the port of Helsingborg have been electrified (interviewee 16). Though, the ships and infrastructure connected to the ships are not owned by the port of Helsingborg, but by the shipping company ForSea. The shipping company also has its own connection to the electricity grid and its own charging infrastructure for the ferries, which was established in collaboration with Öresundskraft. The shipping company does not need permission from the port of Helsingborg to establish charging infrastructure, which is an example of the independence of different actors present in a port.

According to interviewee 16, The port of Helsingborg is in second place in Sweden in regard to electrification, following the port of Gothenburg. As of now all personal cars and smaller work-vehicles such as pickups are electrified, as well as some of the bigger work-vehicles, such as tractors and trucks. Currently, shore side electricity is not available, but it will be by the year 2026. By 2026, 70% of all work-vehicles in the port will also be electrical. Within the area there is also charging infrastructure to charge the vehicles working within the port.

According to interviewee 16, much of the change towards a more electrified operation is driven by the climate goals set by the municipality of Helsingborg. Interviewee 16 further explains that electrification of vehicles improves the work environment for those who operate them, that the investment and operating costs are lower for electricity than diesel, and that hopefully they will need less maintenance as well.

The port of Helsingborg has a gate with opening hours, during which trucks can come to load or unload goods. Before arriving, trucks must give notice to the port that they are coming. Other than this, there is no coordinated logistics or route planning together with the haulages and transport companies from the port. One reason for this is that the haulages and transport companies are not customers of the port of Helsingborg, but the customers of the shipping companies.

Today, there is no charging infrastructure available for incoming trucks, but there are plans of building such. In a collaboration with Öresundskraft, a charging station within the port area will be built by the spring of 2024. Since the port of Helsingborg is governmentally owned, they are not allowed to make profit out of the charging station. Therefore, the collaboration works in a way where the port of Helsingborg grants Öresundskraft land within the port area, where Öresundskraft will build a charging station for trucks. The port of Helsingborg has no responsibility towards the transport companies to provide charging infrastructure, but according to interviewee 16 they see the collaboration as a way of facilitating for the customers of their customers.

Some of the obstacles for further electrification that was mentioned by interviewee 16 are long lead times for charging equipment and vehicles, as well as a general lack of electric effect in northwestern Skåne. As of now the port of Helsingborg does not have any energy storage solutions today, but interviewee 16 means that it might be one possible solution for future problems with lack of capacity, and possible peaks in the need of electricity due to demand for charging.

5.7.3 Analysis of maturity of technology

Many of the findings regarding maturity of technology in the context of electrification of trucks and the transport industry made in case 1 is relevant in this case as well.

As noticed during the interviews, at some sites there are issues of not having enough available capacity at the site, and in these cases a prioritisation might need to be made. As of now, the focus in the cases of ports seem to be mainly on making sure that shore side electricity can be provided, as in the port of Ystad for example. This might lead to a situation where there is not enough available capacity for both providing shore side electricity and building infrastructure for charging electric vehicles. Therefore, the prioritisation of shore side electricity might have a slowening effect on the building of charging infrastructures and other electrification efforts. However, this is something that mainly is a problem for logistic hubs that are ports, and might not be a problem applicable on other logistic hubs. Though, there still might be an issue of prioritising available capacity between different needs of electricity in other logistics hubs. As was stated previously, a number of ports in Sweden have begun using shoreside electricity, but far from all. Also, even the ports that offer shoreside electricity do not provide it for all docks. This places shoreside electricity somewhere in the beginning of the S-curve, to the left of the steep part of the curve. As the adoption of the technology moves towards the right, and passes the steep part of the curve, it is likely that ports shift focus to other kinds of electrification as well.

One solution to the lack of electric capacity that some logistic hubs might be facing, could be energy storages in the form of batteries. In that way, extra capacity could be provided when there is a high demand for electricity, either for charging of electric vehicles, or other usages, such as reserve generators. In this way, the battery can be an extra source of electricity when the capacity is scarce, or much electricity is needed at the same time. At other times, when the demand for energy is lower, for example during the night in the case of a logistic hub, the battery could be used to create income by providing support services or other forms of energy trading.

One pilot project where a similar solution is being tested is located in Väla shopping mall in Helsingborg, where a battery has been placed in order to create a virtual power plant (Energimyndigheten, 2020). The battery is connected to the cooling system, and also provides FCR-D and FCR-N on the balance market. This is a technology that might also be of use for several logistic hubs, where the demand for charging most likely will be unevenly distributed during the 24 hours of a day. According to interviews, there will be high peaks in charging demand during certain hours, and then very low demand the rest of the time. During these hours of dense traffic and high demand of charging, the battery could be used, and during times of low demand it can be used for other purposes.

According to Svenska kraftnät, batteries providing support services on the balance market is a quite new phenomenon (Svenska kraftnät, 2023j). Svenska kraftnät has a pilot programme running as of now, where batteries provide FCR-D and FCR-N, with the purpose of expanding the number of resources qualified to participate on the balance market. While the battery itself is not a new technology, using it for both energy storage and providing support services can be considered more novel. Therefore, the technology of using batteries to provide support services could be placed at the beginning of the S-curve.

Regarding the electrification of maritime traffic and boats, the technology development still seems to be in the very beginning of the S-curve. According to interviewee 7 and 14, there are basically no policies and regulations regarding the electrification of maritime traffic as of now, which may also be one explanation to why the electrification still has not come as far as for transport on land. Though, many of the obstacles in electrification of maritime traffic seem to be a bit more challenging than those for land-bourne transport. At present, there is a limited number of distances and usage patterns for which electrified ships are a sensible alternative. Therefore, there is a risk that the adoption of electrified maritime vessels might reach the stage in the future which Moore (2014) calls "the chasm", where the adoption of the technology stops. To cross this "chasm", further development of technology might be needed, widening the possible usage-cases for electric ships and thus reaching new customers.

While many agree on the fact that electrification in the maritime transport industry will increase in the future, it might not be the only solution to replace fossil fuels in this industry.   For some types of routes and vessels, electricity might be the best solution, but when in the context of big vessels travelling long distances, there might be solutions and fuels better fitted for these conditions (Interviewee 7, 2023) This might mean that maritime traffic might never, or at least not in the foreseeable future, be electrified to the same extent as transport on land.

In summary, there are many different technologies affecting the total electrification of a logistics hub, particularly a port. The different technologies are at different stages of maturity, though most have in common that they are in an early phase.

5.7.4 Stakeholder analysis

There are many different stakeholders having an interest in the operation of the port. As previously mentioned, stakeholders can be divided into external or internal stakeholders, and within the group of external stakeholders, further categorisation can be made into economic stakeholders, socio/political stakeholders and technological stakeholders. In order to further sort stakeholders into different categories the power/interest matrix can be used. As there are many actors dependent and affected by the operations of the logistic hub, this leads to many stakeholders with a high level of interest. As a result, there are many stakeholders in this case being identified as either key players or stakeholders to keep informed in the power/interest matrix.

There are several external stakeholders affecting the operations of the port. Planning of routes and transports of goods is done by haulages, transport companies and shipping companies themselves, with little to no coordination from the port. Since the port has a big number of logistics actors that affect one another's operation and thus the outcome of other actors' business, it is likely that they have some interest in each other's strategies. The level of power that they have over each other can vary, but can in general be considered quite low since they operate separately from one another. However, some of the actors are to some extent dependent on the initiatives of others. For example, if a logistics company wishes to charge their vehicles during loading and unloading of goods, they are dependent on other actors having taken initiatives to set up charging infrastructure. But as was found from the interviews, no actor has an obligation to follow such a wish. This means that in the efforts to electrify one's operation, the different actors often have both high interest and power in each other's strategies, making them key players.

Another type of external stakeholder with a high interest in the operation are the companies shipping their goods through the port, as well as the companies and persons that are waiting for and receiving the goods shipped through the port. These stakeholders could be classified as economical stakeholders, and in the power/interest matrix they could be categorised as stakeholders to keep informed. These are stakeholders who have a high level of interest in the process, as the goods shipped are what generated their income, but at the same time they probably have limited power, since the shipping itself often is managed by transport companies, which distances the stakeholders from the operation itself.

The Swedish government could also be classified as an external stakeholder. In 2022, the total worth of Sweden’s export to other countries was 3 140 billion SEK, and 70 % of Sweden's total export is of goods (SCB, 2023). As previously mentioned, approximately 95% of Sweden's export of goods passes through ports, which makes the operations of ports an important part of Sweden's economy. The Swedish government also has an interest in the electrification of the port, since it is one way of reaching the environmental goals set by the government and the EU. However, as of now, there are no policies or regulations regarding electrification of transport by sea, set by the government. Therefore, the Swedish government could be considered a political and economical stakeholder.

When categorising the Swedish government in the interest/power matrix, the government could be considered somewhere in between a key player or a stakeholder to keep informed. As export is such a big source of income for the country, and reduction of greenhouse gases in the transport sector is an important part of reaching the climate goals, it can be argued that the level of interest from the government is high. In regard to power, it can be considered both high and low. In one way it is obvious that the government possesses a high level of power, being the legislative force in the country. However, when it comes to the day-to-day operations of the port, the government does not exercise the same level of power as some other key players. Therefore, the Swedish government can be considered a stakeholder to keep informed, as long as they are pleased with the way things are running, but if the government decides to change laws or introduce regulations, then they should most definitely be considered a key player.

Two external stakeholders closely related to the electrification of the port are Svenska kraftnät and the owner of the electricity grid at the site and in the area. These stakeholders could be considered both economical and technological. As the electrification proceeds, the character of the relationship could also change, as an increased collaboration might be needed. For example, by selling support services, the operations of the port could also contribute to the operations of Svenska kraftnät. The level of power the grid owners can be considered high, since it is vital to have access to enough electric capacity to be able to electrify operations. Also, as was found in the case, the grid owners can have collaborations with either the port itself or actors active in the port. The level of interest from the grid owner could generally be categorised as relatively low, which would make them a stakeholder to keep satisfied. However, depending on the size and impact of the electrification and potential partnerships, the level of interest might increase, making them a key player.

An example of another relationship between stakeholders that has changed due to electrification, is that of the relationship between the port of Gothenburg and Circle K. Traditionally the relationship between a port and a gas station would be of low interest and low power. However, in this case, where Circle K is providing charging possibilities for electrical vehicles inside the port area, as a collaboration with the port of Gothenburg, this dynamic changes. There are no other charging stations within the area, making the Circle K charging station an important part of further electrification. Therefore, the port of Gothenburg and the Circle K charging station could be considered a kind of key players for each other.

When analysing the stakeholders, it can be seen that the more connected and complex the system, the more dependent and affected the stakeholders becomes by each other's strategies and operation. It can also be seen that when technology moves more towards increased electrification, this also leads to changes in the traditional relationships between different actors.

5.7.5 Value network analysis

As of today, some value network activities can be observed in the operation of the ports, for example the partnership between Circle K and the port of Gothenburg. However, in some cases, the actors are working quite uncoordinated, and there might be ways to improve the operations by increased coordination, making it even more effective. If the stakeholders worked together more closely in a network-like approach as Alle (2000) suggests, it is very likely the amount of value created could be increased.

As mentioned, there are many stakeholders involved in the operations of a port, which means that there is a value network consisting of many roles. This opens up for many opportunities and possibilities to create value, but it can also make the network more complex. If knowledge and other resources could be shared in a more effective way, it would possibly generate mutual benefits and create more value.

When analysing the ports, some examples of transactions in the value networks can be observed. For example, in both the port of Gothenburg and the port of Helsingborg, a transaction of land has been made to enable the building of charging stations. This kind of effort to share resources and align interests could also further speed up the electrification of the port.

The deliverables enabled by the value networks in relation to electrification, in the case of the logistic hub, are quite similar to the ones in case one. Further electrification and utilisation of energy storages could result in deliverables such as hours of frequency regulation and extra capacity in times of high demand.

As of now, in many cases there is no clear responsible or driver of further electrification, rather most of the actors are working alone with their own initiatives and efforts regarding electrification. If these efforts could be combined, and knowledge could be shared within the network, there might be a chance of speeding up the transition. As stated before, this is a kind of operation where several actors are dependent on the performance of others, which makes it even more important to have a network perspective when forming a strategy. The more complex the operations, the more benefits might be achieved by working together in the process of value creation.

5.8 Case 3 Solar park with battery and charging opportunity for vehicles

As was found from interviewee 6, interviewee 8, and interviewee 10, the lack of public charging infrastructure leaves a vacancy for new actors to step in and establish charging points. It was also found from interviewee 6 that when they, together with a customer needed new charging infrastructure, it was not clear who would do this investment and at whose site. In the end, the customer made the investment and did then sell charging of electricity both to the transport company, and to other actors that make deliveries to them. As previously mentioned, in the ports, it was seen that there was no clear role or actor with responsibility for ensuring that there is charging infrastructure on site to support the electrification of heavy vehicles. It can therefore be seen that there are new roles to take regarding providing charging infrastructure, and old roles do not necessarily apply. New actors can take on roles that previously have been strictly designated to specific actors.

5.8.1 Characteristics of a site with a solar park

In this case, a site with a solar park will be investigated. A solar park can both stand alone, producing energy and feeding it into the power grid, and might also be combined with other functions and activities as a part of a bigger energy system. In this case, a solar park will be combined with charging for heavy transport, as that is the focus of the thesis. Unlike the previous cases, this case is not based on specific existing sites, but is more of an investigation of how various elements from different sites can be combined into one. The aim of this is to find synergy effects and explore what a site could potentially look like in the future.

There are several different factors affecting the investment cost of a solar park (Interviewee 2). In a development budget for a solar power plant there are many large fixed costs that are hard to escape. The choice of location can affect the total cost significantly (Interviewee 2). If a site has some kind of large spare area, such as a roof, solar panels can then rather easily be installed there. If this is not possible or there is no building or land on the site with suitable placement, the solar park can be placed somewhere else.

If someone is interested in building a solar park at a specific place, and the place lacks capacity, then a request can be sent in to the owner of the power grid to expand the capacity (Interviewee 2). Then the grid owner will send back a prize for the expansion, and then it is up to the one interested in the solar park investment to assess if the cost is too high or if it is acceptable within the budget. It does not matter what actor owns the local power grid at the place of interest, since there are regulations making sure the ones that own the power grid cannot favour any specific actors (Interviewee 2).

According to Interviewee 2, there is a good business case for using a battery connected to a solar park as a frequency reserve. This can potentially give revenues of substantial value. Moreover, a benefit of such a solution is that the battery can be charged “for free”, from energy extracted from the solar park. Another advantage of connecting a battery to a solar park is that the existing connection to the power grid can be used for the battery as well.

In order for electrification of vehicles to be sustainable, the electricity needs to come from green and renewable sources. Many actors have visions for future energy systems with solar power integrated, charging their vehicles and supplying the sites with green electricity (Interviewee 1; Interviewee 6; Interviewee 10). Combining solar power, energy storage and charging infrastructure could therefore be a way of supplying green and renewable energy for heavy transport.

5.8.4 Analysis of maturity of technology

There is one site today which has a large battery connected to a solar park, that does frequency regulation (Alight, 2022). Therefore, it can be seen that the technology for connecting batteries to solar parks, and providing frequency regulation is available, but not many actors do it so far. Hence, this technology bundle can be considered to be in the very beginning of the S-curve, in the innovator stage of TALC. As more actors become aware of this source of revenue, it is likely that the numbers of actors will increase, moving the technology further to the right on the S-curve.

As was described by interviewee 13, second life batteries from heavy vehicles still have potential to act as energy reserves after they are considered worn-out in a vehicle. Moreover, they are a good fit for storing leftover energy from solar parks, and for providing FCR-D, FCR-N and FFR. With this said, use of second life batteries is today a not yet well known and researched area, nor a common solution. But it is possible that it will become more common ahead, since it could both lead to decreased cost of energy storage and more effective use of resources. Second life batteries from heavy vehicles as large energy storages can therefore be placed at the very beginning of the S-curve where only innovators have adopted the technology.

A solar park in itself can be considered a more mature technology than a solar park in combination with energy storage. The number of solar parks has increased 600% between the years of 2017 and 2021 (Björnsson et al., 2022). This corresponds to an increase in installed effect from 231 MW to 1500 MW, which is equal to 690%. The largest increase was found to be in the case of sites over 1 MW (Björnsson et al, 2022), where the installed capacity increased by 1500%. According to a short-term forecast from Energimyndigheten (2023c), electricity produced from solar energy will increase from 1,1 TWh in 2021 to 5,4 TWh in 2025. This places solar parks somewhere in the steep part of the S-curve, and the total amount of installed capacity can be expected to further increase.

Regarding the analysis of maturity of technologies of electric vehicles and charging, what was described in 5.6.4 apply for this case as well.

5.8.5 Stakeholder analysis

This third case takes on a more holistic and hypothetical approach and discusses a future more potential system of stakeholders, and their potential roles. This analysis will consider a solar park with both a large energy storage in the form of a battery, and charging possibilities for heavy vehicles. Some of the relevant actors in the case is therefore owners and operators of a solar park, owners and operators of the battery (which can be either the same as the one for the solar park, or an external actor), haulage contractors that come to charge their vehicles at the charging station, suppliers of batteries, owner of local power grid and Svenska kraftnät. Most of the stakeholders can be considered economic, since most of them deliver some kind of monetary value to one another. Suppliers of batteries and the infrastructure can be considered technological stakeholders, as well as Svenska kraftnät and competing sources of frequency regulation, since they affect the market and adoption of large batteries as frequency reserves on the FCR-D and FFR market. Moreover, haulage contractors and their pace of electrification affects the need for public and semi-public charging, hence the development of the market for public charging. This means that haulage contractors can be considered both economic and technological stakeholders.

Within the context of the case, actors can take on different roles and develop different relationships. For example, a solar park can be owned and operated by the same actor, or an external actor can do the operation of the park. If there is an external operator, the owner and operator can be considered key players to each other since they have high power and interest in each other's strategies and activities. An energy storage at a solar park can either be owned and operated by the owner of the solar park or by external actors. In the case of an external actor, they can be considered either a key player, if the solar park is dependent on the battery and extra storage of energy. However, the owner and operator of the battery could be considered having low power over the operation of the solar park, but still high interest, placing them in group B- keep informed. A supplier of large batteries could be considered having both low power and low level of interest, meaning they belong to group A-minimal effort. However, at this stage, suppliers of very large energy storage might not be so many, and they might therefore have more power than can be expected, due to limited competition. Moreover, since using these sizes of energy storage at certain sites is a rather new thing, these actors might come together in pilot projects, which can lead to increased both power and interest, and thus making these stakeholders key players as well.

Since solar power has become an increasingly bigger part of the total energy supply, solar power parks have become increasingly important for the owners of the power grid, and Svenska kraftnät. This means that solar parks can be considered having high influence on the supply and stability of the power grid, and thus, making them key players for both Svenska kraftnät and the owners of the local power grid. Moreover, as a solar park with an extra energy storage can help contribute with frequency regulation, the interaction between these actors increases. The solar park is also dependent on its relationship to power grid owners, since they need the proper connection to the power grid so that they can distribute the produced energy, and provide support services. This makes the key player-relationship go both ways.

In this case, haulage contractors and potentially bus operators will be the main customers for the charging station part of the site. The nature of the relationship between the owner of the solar park with charging and the haulage contractor or logistics company can vary, based on their level of involvement. The charging station can either be operated as a public charging station, available to all actors, as a semi-public charging station with some kind of pre-rented spots, a booking system or another kind of contract with a limited number of actors, or finally, as a private charging point that is built in collaboration with one or few other actors. In the case of a public charging station, the relationship can be considered low power and low interest, placing the stakeholders in group A- minimal effort. But if there is a limited number of actors on the market, the influence and interest between these actors increases. Instead, if the charging station is made in collaboration with one or few actors, then they have both high power and high interest in each other, turning them into key players.

5.8.6 Value network analysis

As has been discussed regarding value networks in the previous cases, more integrated and closely related energy systems and value networks are starting to form, and can be expected to continue to do so in the future. This means that it is likely that stronger value networks including more actors will be seen. Also, it has been found that it is probable that value networks have become increasingly important with regard to electrification, and that they are beneficial for the successful adoption of the new technology.

Allee (2008) states three elements for mapping of a value network. Roles, which is the first element, has been analysed under section 5.8.5. Regarding transactions, it can be seen that more activities and value is exchanged between different actors in the value network than before. In this case, an example of an actor combining different services and activities is investigated. This actor will be both a producer and a consumer of electricity at the same time. This shift towards being both a supplier and a consumer is something that was lifted in several interviews as increasingly common. What this means is that the solar park will produce electricity that both can be consumed at the site, used via an energy storage for frequency regulation, and also to feed to the power grid. It is also possible that energy from the power grid will be used in the charging station. Exactly how this whole system will be organised is however not covered in this thesis, since it is besides the scope and left for future research.

Some of the actual deliverables that the solar park can deliver to its value network is frequency regulation, charging capacity, and electricity to the power grid. Depending on the choice of arrangement regarding energy storage, and whether the charging will be offered as public, semi-public or will be in exclusive collaboration with one or few actors, then the value network and the actors within it can look different. Exactly what the arrangement will look like will not be determined in this thesis, but it can be seen that it will affect the number of closely involved actors. According to interviewee 17, an expert in e-mobility at Power Circle, a lot of financial support has been given to public charging, and this has resulted in a solid and strategic base of public charging infrastructure starting to take form. The interviewee means that less financial support has been handed to semi-public and private charging infrastructure, and thus, charging infrastructure at private sites might be lacking in the future. If this is the case, then perhaps the site that is discussed in this case will be built in collaboration with a few actors to supply their vehicles as a home depot.

This case represents a site that aims to take part in a more holistic energy system, and to provide a bundle of different possible services to create value for both the site itself but also the local power grid, the transmission system and transport companies.

5.9 Analysis of potential additions and differences in the business model for a site with frequency reserves

This section will analyse potential elements that will be added to the current business model for a stakeholder with frequency reserves. This will be done in regard to such an actor starting to deliver support services, in particular frequency regulation. The currently existing components of the business model will only be discussed if they change due to the addition of frequency regulation services. Also, the section will not discuss all components of a business model but rather a number of them, where interesting differences and additions were found.

Value proposition

Electrification and available energy reserves at sites opens up a possibility to provide a new kind of value proposition, to offer available capacity in order to help maintain the frequency stability of the power grid. This value offer competes with other value offers that can be delivered from a battery. In the case of the overnight depot, either the energy reserve can be used for frequency regulation, or it can be used to power the vehicle and deliver goods. Therefore, a tradeoff between providing these different value propositions may occur.

Customer segments

The value proposition to provide capacity for frequency regulation is directed to Svenska kraftnät, who is the only actor acquiring frequency regulation today. Svenska kraftnät can be considered a new customer of the sites described in the cases, since they regularly have not sold services or goods to them before. However, a solar park might already sell electricity and other balancing services to Svenska kraftnät. In this new customer segment, Svenska kraftnät is the only customer, and therefore, the sites are dependent on Svenska kraftnät accepting their bids. The companies need to be able to match the price on the market in order to have their bid chosen by the customer. If not, then there is no other actor to sell the service to.

Customer relationships

As have been discussed previously, electrification and more holistic and interactive energy systems, has fostered new customer relationships where both the site with energy reserves and the grid owner can be considered both suppliers and customers to one another. This increased interaction leads to a need for tending more closely to these relations. As was found from many interviews, relationships between many different actors within the value network has become increasingly important with electrification. This means that customer relationships, and the way they are managed, increases in significance as well.

In some cases it can also be observed that the nature of the relationships changes as the electrification proceeds. Some relationships that previously were considered strict customer relationships might turn into relations more similar to what would be categorised as key partnerships. One example of this was observed in interview 15. In this case, ICA, who previously was a customer of haulages, purchases electric trucks and leases them to the haulages to be used to deliver ICA's goods. This means that ICA takes the risk and cost for the investment, instead of the haulages that might not be able to do so themselves. In this way, the haulage's relationship with ICA changes from more of a traditional customer relationship into a key partnership.

Key partnerships

Also, as seen previously, many stakeholder relationships have turned into key partnerships with electrification and a more holistic energy system. According to Osterwalder and Pigneur (2010), there are four different types of key partnerships. Examples of key partnerships that have been identified are in many cases a strategic alliance between non-competitors, to exchange knowledge and foster development. Also, buyer-supplier relationships to assure reliable supplies can be found. An example of this kind of partnership can be seen when charging infrastructure is established in cooperation between a customer and supplier of electric transport, to ensure that there is a reliable supply of charging and that the best solution for it is chosen.

Key resources and activities

To supply frequency regulation in the context that is discussed in this thesis, an energy reserve, specifically a large battery, and some additional equipment is needed. Therefore, a battery becomes a new key resource in the business model, and using it as a frequency reserve, a key activity. This activity also includes planning what hours it will be available, and making sure it has the proper capacity, both for providing frequency regulation during the intended hours, and also to fulfil its other purpose. This means to either have capacity for the full route when the vehicle is collected, or if it is a buffer battery, to have the right capacity to support with electricity when needed at the site.

The fact that the energy reserve has another primary purpose, makes whether to sell frequency regulation or to drive the vehicle a constant matter of trade off, where the earnings from each dedicated hour has to be weighed against one and other. However, there might be other reasons for driving one's heavy vehicles instead of delivering support services, even if the revenues from the frequency regulation market at a certain hour might be higher that from driving the vehicles. For example, a bus operator must drive the intended route, according to the timetable, no matter the alternative revenue. This goes for promised delivery routes in the transport sector as well. Also, one important reason for electrification is to decrease the climate impact from heavy vehicles, so therefore the utilisation of electric trucks might be maximised to increase climate benefits.

New revenue streams

To deliver frequency regulation during hours when a site has available capacity can give new, additional revenue streams. For a vehicle or a battery that is not used during several hours per day, delivering support services to Svenska kraftnät can help shorten the pay-back time, and improve investment calculations. Since it was found in the interviews that it is challenging for many smaller haulage contractors to deal with the larger investment cost of electric vehicles, this additional revenue stream could help make electrification more feasible. Regarding case 3, this thesis explores a more holistic approach to a site, that combines many different kinds of revenue streams, from both the energy provided by the solar park, the battery and from offering vehicle charging. This thesis does not cover exactly how they should be combined to get the most value, but rather explores the possibilities for creating value.

6 Discussion

This chapter aims to discuss the research questions based on the findings from the result and analysis. It begins with a discussion about what actors within the transport industry have potential in delivering support services, and goes on to discuss obstacles and enablers, and the future for the frequency regulation market. Finally, the discussion covers what new roles and gaps within the market there are to fill.

6.1 What actors within the transport industry have potential in delivering support services

6.1.1 Most suitable support services

For all three cases it was found that FCR-D and FFR are the most interesting types of frequency regulation for batteries. This is due to the fact that batteries can meet the requirements on short activating time for these services, compared to other frequency reserves. Also, today there is a high monetary value in offering FCR-D and FFR. In order to place a bid on the market, it must be certain that the battery is available at the said hours, and that it has a proper level of charging to supply the intended frequency regulation. Moreover, for the one supplying the frequency regulation, it is important to know when the batteries will be available, at what charging level and how much power it must have at a certain time after supplying frequency regulation.

Furthermore, interviewee 13 discussed the possibilities to use second life batteries for frequency regulation, and included FCR-N as a possibility as well. Using the battery for FCR-N uses up cycles and wears out the battery at a faster pace than FFR and FCR-D, due to more frequent and longer activation times. Nevertheless, this is not necessarily a bad thing for a second life battery, since the purpose of giving the battery a second life is to use up its full capacity within its calendar lifespan.

6.1.2 Potential for frequency regulation in different segments of the market

In this section, the potential for frequency regulation in different segments of the market will be discussed. This will be done based on the case findings and the factors for case potential.

6.1.2.1 Overnight depot

Based on the interviews in the first case, it was found that driving and charging patterns vary a lot, both within the same organisation, and between different actors. This is partly due to the length of the routes, the number of stops and the type of goods that is transported. Some trucks are in use almost all hours of the day, with three drivers working in shifts. These are often charged around 30 minutes when loaded and unloaded. Other trucks are out on delivery routes during the day and stand in overnight depots during the night, which often is around 16-18 to 05-07. This makes for good predictability. For trucks with such patterns there are hours available for frequency regulation services. There are also those that are charged on site overnight but still need to be charged at some point during the day. It was found that all interviewees saw an interesting possibility in providing such services to obtain some additional revenue streams, if it can be incorporated with the rest of their operation.

It can be seen that some haulage contractors change their driving patterns to some extent when switching to electric trucks. This is often towards more operating hours. When the truck is in operation more hours per day, and does not stand in an overnight depot, but rather charges with fast charging during its route, it is not likely that there are hours available for using it as a frequency reserve.

To sum up the potential for the trucks case, given future possibilities for V2G, there is a good potential for overnight depots to deliver frequency regulation during some hours of the night. This applies only for the case when the trucks stand in overnight depots. For local or regional transports, and longer construction work or similar, then the predictability is good, and the truck schedule is known. For longer transport, it is less certain. The size of the individual batteries, the total number of actors with trucks and buses has good potential. It is likely that in a while, the accumulated capacity of a site will also be significant. Today, even the actors that are in the forefront of electrification do not have that many electric vehicles. But over the coming years, that is likely to change, which could be seen in the cases where all interviewees had new electric vehicles on the way.

Regarding buses, it was found from the interviews that they have a good potential for frequency regulation, both for V2G and potential buffer batteries. The main reasons for this are the fixed timetables and thus very predictable driving patterns and times, the number of buses that will be available at the depot at the same time, and potential hours with available capacity. According to the findings in the case, buses stand in depot fewer hours per night, but the good predictability allows optimisation of the hours in the depot.

Maturity level of technology and market

As was discussed in the analysis, electric trucks can be considered to be in the innovator part of TALC, and electric buses in the early adopters part. This means that both segments are still in early phases of their TALC, and the market can therefore be considered not so mature. However, there is a market, and it is increasing in size. As was further discussed, as electrification moves to the right on the S-curve, then the adoption rate will likely increase, meaning that the electrification will go faster and faster. This will lead to increased accumulated capacity, both at the individual sites and from the total market.

The number of electric truck models available on the market increases, and covers more types of transport. At present, there are models for local and regional distances, and ones for longer distances are under development. Also, a lot is happening with the development of batteries, and there are new kinds of batteries with more advantageous qualities coming. These batteries might also be enablers for V2G, and frequency regulations.

It was found from the interviews that haulage contractors like to operate on experience, which is probably the case for the whole transport sector. This means that these actors, in the process of electrification, wish to start with one or a few pilot projects and wait and see how they turn out, and draw conclusions and learn lessons from these before doing further investment. From two of the interviews with transport companies, it could be seen that driving and charging patterns and behaviours were uncertain in the beginning but that they now have learned both where to charge and when, and how to operate the electric trucks in the best manner. Since the battery is considered a key resource, both for electrification, and also for support services, learning how to best take care of the battery, and how to charge to maintain its capacity as much as possible is a part of the driver's learning curve. With increased knowledge within the transport sector, uncertainties that today might restrain the pace of electrification, can be eliminated and thus speed up the development.

From the interviews it was found that there are some available route optimisation services available today, but that not all use them. It is possible that these will come more in the future, and thus provide more security for the drivers, and erase their concerns regarding access to charging and route layout.

The technological and regulatory development regarding V2G for electric buses and electric trucks will have a high impact on the potential for both cases. As long as manufacturers do not unlock the possibility to provide V2G, and policies and regulations are not developed so that there are standards for how V2G should be conducted in heavy vehicles, there is not yet a potential in the case. It was however understood from the interviews that it is likely that V2G will be possible in the future, but that it is unclear what stakeholders will take the first enabling steps. There are some uncertainties with V2G that need to be dealt with, and there needs to be a clear division of responsibilities, such as where the smart unit that controls the battery and the frequency regulation should be placed. Vehicle manufactures means that V2G is not yet a prioritised technical issue, since they cannot see the demand from the user-side. Also, there are other technological challenges that are more urgent to investigate, but with a more matured technology for electric vehicles, and with an increased market and demand, it is possible that V2G will be enabled.

6.1.2.2 Logistics hub

As noticed, the potential for V2G for trucks coming to load and unload in the case of the logistics hub is very low, for several reasons. The trucks are normally not staying longer at the hub than the time they need to load and unload their vehicles, and it is not particularly likely that the trucks will be parked long enough to provide frequency regulation. In addition, it has also been observed that there might be a potential future issue that the demand for charging will be particularly high during certain times during the day. Due to the high demand, trucks are not likely to stay at the charging point longer than just the time needed for them to charge. The time that external trucks potentially are connected to the grid in a port makes V2G an unsuitable solution.

From this point of view, there is a much stronger case for using an external battery for providing support services in the case of the logistics hub. The external battery can be used to provide extra capacity when it is needed, for example during rush hours, or times during the day with particularly high electricity prices. Then, during other times which are less busy, the battery can be used to provide frequency regulation.

However, for the vehicles used internally in the port, there might be a case for V2G. Depending on the operating hours of the hub, there might be scheduled windows of time where they are not being used, during which frequency regulation services could be sold. For these vehicles the time connected to the grid might be sufficient for both charging and providing support services.

Maturity level of technology and market

As the development of electrification continues, more actors might face capacity shortage at their sites. As of now, it does not seem to be common to have some kind of energy storage at the site to overcome this problem. But as the demand for electricity at sites like these will probably only increase during the coming years, more actors might run into problems and the ones with capacity shortage must find some solution to it. This could potentially lead to an increased adoption of the kind of energy storage solutions that has been discussed in this thesis.

When considering the potential for frequency regulation in regard to maritime vessels the main issue might be the maturity of technology. Firstly, there still are a quite limited type and number of bigger boats that are electrified. Also, the development of making V2G possible will probably also be slower in boats than in heavy trucks. Even though there might be potential in this case when considering size of storage and predictability, depending on the function of the boat, the potential still can be considered bigger in connection to the land-borne traffic in the hub. The working vehicles of the hub are starting to become electrified, to some extent. The market for electric working vehicles can be expected to mature since they, according to interviewee 16, seem to have potential in being more financially beneficial than for fossil fuelled ones.

6.1.2.3 Solar park with charging opportunities for vehicles

In the shift towards renewable energy sources, solar power has become increasingly popular. A solar power plant can be used for different applications, both to feed electricity to the power grid, to supply a household or a site with energy, and also to fill batteries to store the energy for later usage. This stored energy can then be used for various things. One application that can be beneficial is to use the stored energy for frequency regulation. Today, large batteries connected to solar parks are not so common, but it can be seen that there are some projects testing this, and that this type of solution might be seen more in the future.

It was also understood from the interviews that more and more sites and companies want to invest in more holistic energy systems, where a solar park, often on the roof, is a common component. In this energy system, it is not unlikely that there might be a battery connected that can store energy for when it is most needed. This might be when there is a shortage of capacity from the power grid, or when the sun is not shining and the solar panel does not supply energy. If there are revenues to obtain from using this battery as a frequency reserve, then it is likely that this can be done during hours when it is not needed for feeding energy to the site. As found from the interviews, it is then most beneficial to supply FFR and FCR-D. As described before, in order to be able to provide both upwards and downwards FCR-D, the battery should be kept at around 50% charged. This implies that in order for the battery to be able to supply both, it cannot be needed at a fully charged state directly after hours bid into the frequency market.

There has been a gap identified in the market that is supply of charging capacity, which could potentially be filled by a site with all above described components. Whether this site is placed in the middle of a logistic dense area, on a rooftop at a logistics site, or out on a field alongside a road, is not determined in this thesis, but a potential for all can be seen. As has been discussed, charging at such a site could be offered both in a public, semi-public or a private context. The potential benefits with the alternatives can vary, but no matter the choice, the case has good potential in both providing frequency regulation in combination with other value creating activities.

Maturity level of technology and market

In this case, there are several rather new technologies and bundles of technologies that might come to play an important role in future energy systems. Even though the total share of solar energy produced in Sweden today is relatively small, it is increasing fast. Batteries are not a new technology, but some of their applications are new. Currently, there are not many large solar parks that use big energy reserves, especially not for frequency regulation. Also, some of the frequency regulation services are quite new, such as FFR and downwards FCR-D. Therefore, the market for using batteries as frequency reserves is not yet very mature, but is developing. It is not certain exactly what the market will look like in the coming years, and how the supply will meet the demand. What can be said is that there is a good potential to be found in the case at present and likely in the coming years.

Furthermore, there are chargers for both fast and slower charging that are available to set up charging infrastructure. As electrification of heavy vehicles is increasing, more and more charging infrastructure is established. This is done both at private and public sites. Despite this, the market is still in an early stage of development. Therefore, the demand and supply can be considered rather uncertain, which was found to be the perception of the interviewees as well. However, since electrification is an unavoidable development according to most, the market will mature and uncertainties will decrease.

6.2 Obstacles and enablers for electrification of the transport industry, and their effect on the possibility to provide support services

The findings from the three cases can provide insights into possibilities and challenges that can steer the development in different directions. Below follows a discussion on a number of relevant obstacles and enablers for electrification of the transport industry, and their effect on the possibility to provide support services.

6.2.1 Increased electrification

It is likely that the demand for green transport services will increase in the future, and as was found from several interviews, electrification is likely to be necessary to take market shares and remain competitive. It is possible that electric transport will become a competitive advantage. Apart from reducing CO2 emissions, electric transports are much quieter, thus delivery does not disturb the city life as much. It is also likely that there will come more regulations in the future regarding fossil fuelled trucks, and perhaps more subsidies for electric alternatives. To not have begun with electrification when such regulations are enforced might lead to big problems, that either can require very large investments at once, or put an actor out of business.

6.2.2 Driving patterns and mindset

Depending on the driving patterns of the electric trucks, the possibility for V2G varies a lot. Some trucks are in operation almost all hours of the day, only charging during 30-minute intervals when loading and unloading. This driving pattern maximises the utilisation of an electric truck, which is what many actors aim for, due to the fact that it is more than twice as expensive to invest in an electric truck compared to a fossil fuelled one. Also, as mentioned, there are a number of advantages of driving electric trucks as much as possible, such as a decrease in negative impact on the environment and reduction of noise and pollution in cities. This means that deliveries can be done in cities at night as well. However, this leaves no room for the trucks to be used for V2G. This mindset of maximised utilisation is new for many actors and has come with electrification. If this mindset will remain, or if actors will go back to driving more regular hours, and not during the night, is not certain. What can be seen is that old driving patterns opens up the possibility for V2G, while new maximised utilisation does not.

6.2.3 Change in ownership and leasing times

From interviewee 9 and interviewee 11, it was found that leasing becomes increasingly popular. This means that fewer own the vehicles that they operate. Depending on whether leasing agreements will allow V2G or not, the market for V2G services might differ. In addition, according to interviewee 11, the leasing time has decreased. A regular leasing time could previously be around 5 to 6 years, but nowadays it is often as short as 3 years. The normal lifetime of a regular truck is 7 to 8 years (Interviewee 8). This could mean that new technology reaches the customers faster if the leasing contracts are shorter, and thus, if V2G is made possible then all electric vehicles can be changed to ones with such technology within 3 years.

6.2.4 Calculations

Electric trucks can cost 2-3 times more than a regular truck (Interviewee 11). This, in addition to the small margins of haulage companies, can cause some problems regarding electrification of the vehicle fleet. The interviewees all implied that it is more challenging to get the calculations to add up with electric trucks compared to old fossil driven trucks. As was previously described, if there are additional revenues to obtain, then this could help shorten pay-back time and strengthen the investment case for haulage contractors.

Since V2G is not made possible today, this is not a real part of the calculations of investment and operation of an electric truck yet. Therefore, as of now, it is not taken into consideration when investment decisions are made. However, in the future it might be a factor favouring electrification further.

As was found from the interviews, it is important for the haulage contractors to make accurate calculations on the purchase and use of their electric vehicles to make the investment feasible. These calculations are often dependent on the price for charging the vehicles, and if the price turns out to be higher than expected, the calculations do not add up. Depending on driving and charging patterns, the calculations vary in sensibility to electricity price at the site, or price of charging at public stations. From the interviews it was found that many haulage companies want their trucks to charge as much as possible at the home site since the price of charging is lower there. However, establishing charging infrastructure can be costly, and if the trucks are charged at the site, they might be in operation less hours than if they fast charge during the route.

According to interviewee 10, 5,95 SEK is the best public charging price they have found per kWh, and prices can be much higher. At the home charging point, the same cost is 2,95 SEK per kWh. This means that costs can be saved from charging at the home site. If the price of electricity varies a lot, the whole calculation might be affected and no longer add up. Having charging infrastructure at the site can help prevent sensibility for changes in price at public charging points, but the changes in price on electricity can still create uncertainties in cost. One thing that is relevant to bring up in this context is that cost of fuel can become an issue for fossil fuels in the future as well. It is even likely that the price of fossil fuel will increase in the future, and it might thus be more uncertain to be dependent on fossil fuel prices rather than price of electricity from public charging stations.

6.2.5 Lack of charging infrastructures

As the electrification of heavy vehicles increases, the need for charging infrastructure, and electric output from the power grid will increase. It is possible that the demand for charging electricity will increase faster than the supply, or at least the possibility of accessing charging. This can then lead to a shortage, both at home sites/depots and also at public charging. According to interviewee 17, there is good financial support to obtain for establishing public infrastructure, but these are mainly focused towards public charging. This was found from logistics companies as well. Some of them and their customers had tried to get financial aid for their charging infrastructure at the site, which some of them received, while others did not.

Charging infrastructure will both be needed in more locations, and on a bigger scale. This means that chargers will be needed both at transport sites, at distribution customers, and along roads. The infrastructure will be needed in many more places to make more roads accessible, and not only on the most common ones. Charging stations will also need to be able to supply an increasing number of trucks. It is of utmost importance for haulage contractors to make their routes on time and not lose time waiting in line at charging stations. The fact that charging with electricity today takes more time than charging fossil fuels is already a challenge for many. This opens up an opportunity for new actors to enter the market and provide charging capacity at strategic places. Also, if charging can be combined with other income generating activities, then such a site can be located where there is a demand, but not yet a large number of customers. This could help push electrification forward and enable new routes for electric vehicles.

From the interviews it was found that there is a general worry within the transport sector that there is not enough public charging infrastructure in place to make all routes. Heavy transport routes are different in Sweden compared to other countries in Europe. Many roads are remote and small, but still important transport routes of various goods. These are less probable to obtain public charging in the near future. Haulage contractors are reluctant to invest in electrification of routes that do not yet have public charging, which makes it seem like there is no demand for charging along those routes. This makes it less attractive to establish charging infrastructure there. Interviewee 6 described a booking system, which could then help with this issue. If the charging points are bookable, then it can be made sure that there will be charging available at a certain time at a certain place.

As mentioned, there are also several initiatives working to increase the number of charging locations for electrical vehicles. Klimatklivet is one of these, providing big sums in support of building new charging stations.

According to interview 18, the EU might also enforce requirements on charging infrastructure in the member countries, to further speed up the electrification of vehicles.

6.2.6 Lack of capacity from power grid at sites

One problem that transport companies might face in their electrification is a shortage of capacity. It was found from the interviews that some sites have a lot of capacity while others are lacking. This can also be seen in the case of the logistics hubs, where one port has sufficient capacity while another already has a shortage of capacity. Moreover, even though many of the interviews were with companies that in some ways are in the forefront of electrification within this market, they still have only taken smaller steps, and it is therefore possible that more actors will face capacity shortage in the future, when they have come further in the electrification process.

6.2.7 Buffer batteries and second life batteries

As mentioned, batteries can be a solution to capacity shortages at sites. This is true for both logistics hubs, home sites for haulage contractors and others. An energy storage can be placed at a site, and charged when the vehicles are not charging or when there is enough capacity from the regular charging infrastructure to supply the vehicles. When there is a peak in demand, the battery can be connected and used as an additional source of charging. The hours that the battery is not needed, and when it is sufficiently charged, it could be used for frequency regulation. This would then presuppose that it is known when the battery will be needed and not.

It was understood from interviews that there is a risk of a peak in demand for charging at certain times during the day, and then a low demand at other hours. This could indicate that logistics hubs would need extensive charging capacity at some hours during the day, and limited at other hours. This opens up an opportunity for using energy storage in batteries, to supply charging during busy hours, and use as a frequency reserve during the rest of the time.

From interviewee 13, it was found that a vehicle battery that is considered worn out, still has around 80% of its capacity left. This means that these batteries can get a second life, as energy storage. This energy storage can be used for many purposes, such as frequency regulation and storage of leftover energy from wind and solar power. Therefore, it can be seen that vehicle batteries can have a value after its said life span. This could add to the value in investing in electric gravy vehicles. This opens up an opportunity to keep such batteries both at different sites as energy reserves, and at a solar park to store energy. In both cases, it can be used on the frequency market, which has been found in the interviews to be the most lucrative way of using such a battery today.

6.3 How can the future for the frequency regulation market, demand and supply be expected to develop?

6.3.1. Uncertainty of market trajectories

As can be seen in the previously presented forecasts, making predictions about the market for, and the price of, frequency regulation services is not an easy task. Even though Svenska kraftnät has pre-decided requirements for volume for some of the support services, there may still be unforeseen costs. One clear example of this is the year 2022. In the forecast presented in figure 9 in 5.3.3, it is forecasted that the total cost of support services would be less than 2 500 million SEK in 2022. This forecast is made in 2020, and the real outcome was costs of over 6500 million SEK.

There are several factors that can have contributed to this vast different between forecast and reality, but the main reason presented by Svenska kraftnät in the annual report from 2022 (Svenska kraftnät, 2023g) was increases in the electricity price and an increase in the volatility of the market. This is something that can be caused by a number of different factors, and maybe even more likely, a combination of several factors. One such factor that has affected the entire European energy market is the decreased energy export from Russia (Naturskyddsföreningen, 2023). Already before the invasion of Ukraine, Russia started to limit the export of natural gas, and after the war started, the export has been further limited, both due to sanctions from Europe, but also due to decision-makers in Russia deciding to limit export as a form of putting pressure on the European countries.

Covid-19 was also something that was incredibly hard to predict, but had a big impact on many many markets, the energy market being one. One effect of covid-19 was a decrease in demand, which lowered the prices of electricity (Svenska kraftnät, 2020). These are examples of factors that can have a huge impact on the price of support services, but might be very hard to predict when making forecasts.

Even though the forecasts presented have not been accurate in regard to the development of costs, there still might be useful implications that can be found when analysing some of the forecasts. Since the forecasts so far have been correct of the direction of the development, even though the numbers are not accurate, there is a possibility that the direction of the market still might be accurate, and that we might see a pattern of decreasing costs for SVK for support services after the predicted peak in 2024.

6.3.2. Demand

6.3.2.1 FFR

FFR is a quite new product on the market, and it is not entirely easy to forecast how the demand and the price of the service will develop in the future. As presented, the cost and need for FFR has varied during the three years it has been available on the market. To some extent, the need for FFR can be planned. For example, certain actions that cause disturbances, such as nuclear power plant revisions or similar activities, can be scheduled in an optimised way, minimising the disturbance it will cause for the power grid. It is also important to take factors in the environment into consideration when analysing the shifts in price between the years. During the three years that FFR has been available on the market, there has been both a global pandemic and the start of a war, both affecting the market in different ways.

In comparison to FCR-D, FFR is a very small market in terms of money spent by Svenska kraftnät. As of now, Svenska kraftnät’s maximum volume of FFR is set to 100 MW (Svenska kraftnät, 2023a). However, this does not necessarily make FFR less interesting from a business point of view. Since the need for FFR is correlated with the amount of rotational energy in the system, this means that in a future where we rely more on renewable energy sources, which do not contribute to the rotational energy in the system, the need for FFR might increase. Another factor that makes FFR interesting in the context of using batteries as a frequency reserve, is the requirement for short activation time. Since not all sources of energy can meet this requirement, batteries have a competitive advantage in this market.

6.3.2.2 FCR

Unlike FFR and some of the other types of frequency regulation services, the need for FCR-D is not affected by the switch to intermittent energy sources. The reason for this is that FCR-D is used in cases of disturbances.

When forecasting the demand for downwards FCR-D, there is not much historical data to rely on, since this is a new product, launched on the balance market in 2022. However, as mentioned, the maximum volume for 2023 is 558 MW for upwards FCR-D and 538 MW for downwards FCR-D (Svenska kraftnät, 2023a). Though as of now, a smaller volume of downwards FCR-D is bought, since the product still is very new. The plan is to increase the volume of procured downwards FCR-D over three years until the maximum volume of 538 MW is reached (Svenska kraftnät, 2023b). This means that even though it is not entirely certain how big the demand for FCR-D will be, it will not be bigger than this pre-decided volume (unless the volume limit is changed in the coming years). This means that there is an upper limit on possible demand, at least for the time being.

6.3.3 Supply

As previously mentioned, the number of pre-qualifications for providing support services has increased drastically in the last two years. Svenska kraftnät also continues to try to make the market more accessible and attractive for potential new suppliers, both through changes in pricing, and through new regulations regarding responsibility. In Svenska kraftnät’s annual report from 2021, it was stated that many potential suppliers were waiting to enter the market until the old balance responsible role had been divided in to the two new roles: Balance Responsible Party (BRP) and Balancing Service Provider (BSP). This change will be made in 2024, which means that an increase in the number of suppliers in the market can be expected by then.

There is also a plan of changing the pricing mechanism for FCR, which as of now is the support service on which most money is spent (Svenska kraftnät, 2021f) (Svenska kraftnät, 2022e). This plan is now being evaluated by Svenska kraftnät, and will come into force in 2024. The price will then be decided with marginal pricing, something that Svenska kraftnät believes will make the market even more attractive for new suppliers, due to the increased earning potential.

There is also a very realistic possibility that the dramatic increase in price that was seen in 2022, in combination with SVK's efforts to reduce the barriers of entry, will attract new suppliers at a higher pace than before. If there is money to be earned, many companies will want to be a part of the market.

It is expected that the supply of frequency regulation services will most likely increase the next couple of years. As discussed above, it might not be the case that the demand increases at the same pace, at least not the demand for FCR-D. If the supply increases at a faster pace than the demand, this will most likely lead to reduced revenues for suppliers, since the supply and demand will meet at a lower price. When the competition increases, more suppliers will be competing over the same volumes, and the supplier who provides the lowest bid will get the deal.

There might be a risk of the market currently being so attractive, that the number of suppliers on the market will increase to the extent of prices being significantly lowered. At this point, some actors might find the profit margin of delivering frequency regulation too small, making the market less attractive.

Plans on changing the requirements for providing FCR-D might lead to some current suppliers no longer being able to deliver FCR-D. For example, as mentioned in interview 12, stricter requirements regarding activation time might make it impossible for waterpower plants (currently by far the biggest supplier of FCR-D) to deliver FCR-D. This will create a need for new suppliers of FCR-D, using other energy sources as frequency reserves.

The need for FCR-D and FFR is somewhat predictable, even though the predictions do not always match the real outcome. However, the future supply and price of these services are less predictable. At present, frequency regulation is an attractive market with high earning potential, but it is possible that it might decrease in the future. Due to uncertainties regarding future supply of frequency regulation, and thus, potential earnings, a short time to market can help increase chances of reaping the monetary benefits of the market before earnings might decrease.

6.4 New roles and gaps to fill

The changes in the market and energy system results in room for new types of value creation and value capture, for both old and new actors. This thesis has identified a number of such through empirical data, stakeholder analysis, value network analysis, and analysis of components of a BMC.

It was indicated in some of the interviews that there is a lack of charging infrastructure at sites, customer sites, along roads and at logistics hubs. If this remains the case, there is a role to fill. This role can potentially be filled by a current actor with a similar previous role, as was seen in the case of Circle K’s charging station by Gothenburg hub. The role can also be filled by a new actor entering the market for fuelling vehicles. This could for example mean that a customer to a transport company, as in one example from the interviews, sets up charging infrastructure at their sites, that can be used by all trucks that come and deliver at their site. Moreover, as was seen in case two, this role can also be filled by an energy company or grid owner. This was seen at the port of Helsingborg, where Öresundskraft will be responsible for operating the charging station. Today, the price of public charging is significantly higher than charging at the home site. If more actors were to enter the market to provide public or semi-public charging infrastructure, then it is possible that this will lower prices due to increased competition, making it less costly to charge publicly.

Increased accessibility to charging could be one way to potentially help the electrification of heavy vehicles. If desired, the charging infrastructure could also be a component of a bigger site-based energy system as is explored in case 3. In order for such a site to take part in the frequency regulation market as well, the site could either use external energy storage, or potentially in the future, make use of V2G.

As described, the frequency regulation market is hard to predict. It was found from several interviews that the uncertainty of both the future demand, future supply, prices and number of actors makes the market both interesting but perhaps also repelling for the risk avert actor. However, today, the market is worth a whole lot, 6 500 million SEK, which is a good incentive for new actors to take part. The possible earnings that can be obtained from providing frequency regulation could give incentives to further invest in electrification.

It has been found in this thesis that there are many different actors that have the potential to provide frequency regulation, for example actors with buffer batteries and energy storages, batteries connected to intermittent energy production, and possibly in the future, actors with heavy vehicles through V2G. One thing that most of these actors have in common is that they have other core activities and capabilities and are therefore not interested in handling the activities that come with providing frequency regulation, such as aggregation of capacity and the bidding. Thus, there is a possibility for external actors to provide this service. In other words, with an increased number of smaller suppliers of frequency regulation, there might be a need for an aggregator to orchestrate these services.

7. Conclusion

This chapter contains a summarisation of the conclusions of the thesis. It also presents a discussion of the validity and reliability of the results and chosen method. The chapter ends with contributions to research and suggestions for future research.

This thesis has investigated the possibilities for using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid, as well as what value that can be created by, and obtained by these sites. Based on an investigation of six factors affecting the potential of a case: *the size of the individual energy storage, the accumulated size of potential market, the accumulated size of realised market, predictability, the time that the energy storage is connected to the power grid, and maturity,* it was found that overnight depots, logistics hubs and solar parks have good potential in delivering frequency regulation. These cases were then further investigated to more thoroughly understand their potential and what values can be created and obtained by these stakeholders.

It was determined that the frequency regulation types FFR, FCR-D and in the solar park case, also FCR-N, are the most suitable types of frequency regulation for large batteries, due to several aspects such as their required activation time, endurance and potential earnings.

Sites that can offer frequency regulation to Svenska kraftnät can create value by providing frequency reserves to maintain the stability of the power grid. This does not only give benefit to Svenska kraftnät, but also to other stakeholders affected by the stability of the power grid. The value that can be obtained by sites with energy reserves is additional revenue streams, a higher utilisation and shortened pay-back time for investments including batteries.

Regarding the three cases, they all have some potential, and some limitations to their possibility in providing frequency regulation. It can also be seen that there are several both obstacles and enablers affecting the pace of electrification and the possibilities for providing frequency regulation. In the overnight depot case, it was found that electrification has led to actors increasing the utilisation rate of their vehicles, which decreases or eliminates the window of opportunity for frequency regulation. However, there are still actors with potential. Bus operators and some logistics companies have predictable timetables and keep their vehicles in overnight depots during the night. These actors have good potential in providing frequency regulation. For logistics hubs, the biggest potential was found in buffer batteries and additional energy storage, and to some extent, V2G for the working vehicles within the hub.

The third case takes on a slightly different approach and investigates the potential of a more holistic energy system at a site. In this case, a solar park is combined with a large battery that both can store produced energy and provide frequency regulation. At this site, charging of electric vehicles can be offered as well, to fulfil a need that was seen in cases one and two. This site will thus take advantage of synergy effects from combining these elements at one site and explore a more futuristic scenario. The value created by the site in the third case would not only be increased supply of renewable energy, and stability of the power grid, but it would also help in the electrification of the transport sector, since limited access to charging, and fear of lacking access to charging restricts the development.

The different cases have varying times during the day when they have potential to provide frequency regulation. Both buses and trucks in overnight depots can only provide frequency regulation during the night, when they are connected to the grid. Depending on when the working vehicles in the port are used, it is likely that they operate most during daytime, and thus can be a frequency reserve during the night. Regarding buffer batteries and batteries as energy storage at sites, they can be expected to have more varying availability hours. If the buffer batteries are used for charging vehicles over the night, then they can be available as a frequency reserve during the day. If they instead are used to supply charging for vehicles at a port during peak demand hours around lunch, then they might have available capacity from early evening and forward.

It has been found in this thesis that the market for frequency regulation is difficult to predict, and that it is not certain that the demand for all types of frequency regulation will increase. This means that time seems to be of the essence in order to benefit from the market. Today, profit can be made providing frequency reserves, which can strengthen the investment case for electrification. However, given the uncertainty of the market development, and increasing supply, prices are likely to decrease, making frequency regulation less profitable.

7.1 Validity and Reliability

Even though measures have been taken to increase validity and reliability of the thesis, there are always some limitations to their extent. The thesis covers only the Swedish market which is quite unique in its nature, and the conclusions are therefore only applicable at said market. Also, even though interviewees were chosen from different parts of Sweden, all their sites are still in the southern parts, meaning that the results might be less applicable in northern Sweden where the level of electrification as well as the conditions might differ, and thus also the supply of frequency reserves.

Moreover, the interviewees were chosen to cover different parts of the population of interest. Still, only actors that to some extents have started electrification of their operation were chosen. This was done to understand underlying prerequisites, possibilities and challenges with electrification and the ability to provide support services, as well as reasons behind investing in electrification. The selection of interviewees does therefore not represent actors that for some reason have a negative view on electrification or has not yet started electrifying.

The interviews were held with open ended questions, which were divided into topic-related parts in an interview guide. Different interview guides were written for each type of actor, which means all ports received almost identical interview guides, and the same goes for the transport companies. One limitation to the data collection is that even if the interview guide was designed to find all relevant data needed to understand the case and answer the research questions, if different questions were asked, then other results might have been found.

A smaller selection of questions were asked to understand different actors' perceived view of the market. The findings from these questions are therefore what the actors perceive the reality to be, rather than what it actually is. This is done to understand decisions, challenges and enablers regarding electrification and frequency regulation.

The interviewees have varying roles within their companies, and this might lead to them having different experiences and levels of knowledge on the topics of the interview. When looking at the data from the interviews, one must therefore keep in mind that the answers are from varying roles and thus expertise and points of views.

The results and discussion of this thesis has partly been built on qualitative data, gathered through interviews and collected and put together by the authors of this thesis. Even though measures have been taken to increase the reliability of the results, there can be some limitations to the extent of the accuracy due to the nature of the method. Quantitative secondary data was collected from sources that were considered having high reliability.

7.2 Contributions to research

This thesis has provided an investigation of possibilities for using batteries in heavy vehicles and charging infrastructure at sites as frequency reserves, to support the power grid as well as an investigation of what value that can be created by, and obtained by these sites. This thesis was done as a case study, which thus also contributes with an embodiment of a number of logistics actors and their level of electrification. This thesis has therefore added new empirical data to existing theory, and hence broadened the validity of theory. Moreover, the thesis has provided an analysis of stakeholders and value networks within the transport industry, especially with regard to electrification and frequency reserves, and an analysis of the maturity of technology. In addition, this thesis has contributed with an analysis of potential additions to the BMC for sites with frequency reserves. Finally, the thesis has identified potential roles to fill on the market.

7.3 Contributions to practice

This thesis provides a deeper understanding of how roles and value networks within the sector of heavy vehicles shifts and changes, as a result of electrification and the possibility to provide frequency regulation. Moreover, this thesis provides suggestions for new and vacant roles in the value network, that can be taken by either existing or new actors. Finally, the thesis provides additions to business models for actors that can provide frequency regulation.

7.4 Suggestions for future research

During the investigation of this thesis, many interesting topics and questions were found, that due to the delimitations and scope of this thesis, could not be further investigated. This leaves several suggestions for future research.

Firstly, a more thorough examination of the chosen cases could be made. For these, a complete business model canvas could be analysed, as well as quantified calculations for each of the cases regarding investments and potential profits.

Moreover, the development and future for the market for support services with regard to the increased electrification and energy transition could be also further investigated and forecasted. Additionally, other cases than the ones that were chosen in this thesis can be investigated regarding their potential for providing frequency regulation.

The technological and legal aspects of V2G could also be further examined, together with enablers, obstacles, and future possibilities for the technological development of V2G. The development and future for V2G for different types of vehicles could also be further investigated.

Another area that could be further explored is the room for, and roles of, new actors on the market for support services, and the gaps that the energy transition will lead to. This can be either ones that have been identified in this thesis, or additional ones. For example, the specifics of an aggregator role of frequency regulation services can be investigated.

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10. Interviewees

Interviewee 1, Business Manager eMobility, E.ON (Conducted 2023-02-16, 2023-03-06)

Interviewee 2, Business Developer, Technical Design of Photovoltaic Power Station, E.ON (Conducted 2023-03-06)

Interviewee 3, Senior Commercial Business Developer, E.ON (Conducted 2023-03-09)

Interviewee 4, Responsible for the Balance Market, Svenska kraftnät (Conducted 2023-03-10)

Interviewee 5, Expert in solar parks with batteries (Conducted 2023-03-22)

Interviewee 6, CEO, LBC (Conducted 2023-03-28)

Interviewee 7, Head of Innovation, Göteborgs hamn (Conducted 2023-03-30)

Interviewee 8, Business Area Manager for logistics and environment, Alltransport (Conducted 2023-03-31)

Interviewee 9, Director Business Development, Volvo (Conducted 2023-04-03)

Interviewee 10, Key Account Manager, Erikssons åkeri (Conducted 2023-04-03)

Interviewee 11, eMobility Manager, Veho Import (Conducted 2023-04-03)

Interviewee 12, Senior Market Analyst, One of Sweden's biggest Waterpower Suppliers (Conducted 2023-04-03)

Interviewee 13, Expert at second-life for batteries from heavy vehicles (Conducted 2023-04-21)

Interviewee 14, Environmental and quality officer, Ystad Hamn (Conducted 2023-04-24)

Interviewee 15, Strategic logistics developer Transport, ICA (Conducted 2023-05-04)

Interviewee 16, Technical manager, Helsingborgs hamn (Conducted 2023-05-08)

Interviewee 17, Expert E-mobility, Powercircle (Conducted 2023-05-08)

Interviewee 18, Fleet director, Keolis Sweden, (Conducted 2023-05-03)

Appendix

Intervjuguide 1

Tekniskt

- Vad behövs av en laddare för att den ska kunna frekvensreglera?
- Vad krävs av batterier för att frekvensreglering ska vara möjligt?
- Vad krävs av fordonet för att frekvensreglering ska vara möjligt?
- Hur stor andel av de laddare som redan finns idag kan användas för frekvensreglering?
- Hur ser den tillgängliga infrastrukturen ut idag? Hur många platser finns det idag som har möjlighet att användas till frekvensreglering?
- Hur stor investering rör det sig om när det kommer till att investera i utrustning som möjliggör frekvensreglering?
- Skiljer sig laddare för bilar och bussar i styrka och egenskap?

Intervjuguide 2

Frågor gällande val av case

- Hur stor del av den energi som produceras i en solcellspark idag säljs på elnätet? - Går energi förlorad ibland för att den inte används/kan säljas?
- Hur mycket energi går förlorat om den energin som utvinns används för att ladda ett batteri istället för att skickas direkt ut på elnätet?
- Hur tror du att utvecklingen för solcellsparker kommer se ut om 5 år?
  - Hur stor del av sveriges el kommer komma från solceller?
- Hur tror du att utvecklingen för solcellsparker kommer se ut om 10 år?
  - Hur stor del av sveriges el kommer komma från solceller?
- Vet du hur vanligt det är att det finns batterier kopplade till solcellsparker?

Frågor gällande case

- Hur mycket energi kan man få ut från 1 m2 solcellspanel?
- Hur lätt eller svårt är det att förutspå hur mycket el som kommer produceras av en solcellspark en dag eller en timme?
- Hur mycket varierar elproduktionen vid olika väderförhållanden?
- Hur mycket varierar elproduktionen mellan olika årstider?
- Vilka faktorer påverkar kostnaden vid investering i en solcellspark?
  - Vilka underhållnadskostnader har en solcellspark?
- Är det möjligt att anlägga en solcellspark som laddar batterier som sedan kan användas för att ladda fordon, som en laddstation? Om ja:
  - Vad skulle det finnas för fördelar med en sådan lösning?
  - Vad skulle det finnas för nackdelar med en sådan lösning?
  - Finns det liknande lösningar i Sverige eller utlandet idag?
- Om E.ON skulle vilja implementera en sådan lösning, vilka aktörer skulle de behöva arbeta tillsammans med och varför?
- Vad krävs av en plats för att den ska vara lämplig att anlägga en solcellspark på? - Vad krävs av infrastrukturen på platsen?

- Finns det några geografiska begränsningar för var E.ON skulle kunna anlägga en sådan park?
- Vad kan man tjäna på att sälja en kWh el till nätet?
- Vad kan man tjäna på att låta ett fordon ladda en kWh el?

Intervjuguide 3

Vilka krav som finns på batterier för att de ska kunna användas vid frekvensreglering

- Hur påverkas ett batteri av att användas till frekvensreglering?
  Hur påverkas dess livslängd?
- Kan alla typer av batterier användas för frekvensreglering?
- Vad behöver man koppla till batteriet för att det ska
  kunna användas för frekvensreglering?
- Kan man frekvensreglera både upp och ner med ett batteri, eller bara upp? - Kan man använda ett batteri till flera olika funktioner, tex både spotpris-optimering och frekvensreglering?
- Kan man använda batterier för alla typer av frekvensreglering,
  eller bara vissa? (aFFR, mFFR FCR-N, FCR-D (upp och ner), FRR)
- Är vissa typer av frekvensreglering mer lämpade för batterier än andra?
- Hur stort bör batteriet/samlade kapaciteten av ett antal batterier var för att det ska vara en intressant resurs för frekvensreglering?

Vilka krav som finns på elnätet och dess infrastruktur vid frekvensreglering

- Kan E.ON erbjuda frekvensregleringstjänster på platser där de inte äger elnäten? - Om ja, krävs det något slags samarbete/tillstånd med nätägaren?
- Vad krävs av elnätets infrastruktur för att frekvensreglering ska vara möjligt?

Lite övergripande om utrustning och teknik som krävs för frekvensreglering

- Finns det någon annan utrustning som behövs för att kunna frekvensreglera? - Vilka andra resurser, förutom batterier, kan användas till frekvensreglering? - Vilka typer av frekvensreglering skulle vara mest aktuella för E.ON? - Säljer E.ON någon typ av flexibilitetstjänster i dagsläget?

Intervjuguide 4

Frekvensreglering

- Hur ser behovet av frekvensreglering ut idag?
- Vad finns det för källor (tex batterier) och tillvägagångssätt för att reglera frekvensen idag? - Vilka källor tror ni kommer finnas om 5 & 10 år?
- Varierar behovet av frekvensreglering under dygnet/årstider osv?
- Är det geografiskt begränsat på något sätt, alltså kan källan till frekvensreglering finnas var som helst eller måste den vara i samma område som behovet?
- Hur ser ni på behovet av frekvensreglering i framtiden?
- Vad innebär uthållighet? (FCR-D har en uthållighet på minst 20 minuter tex) - Används flera typer av frekvensreserver samtidigt? Finns det en samverkan mellan olika typer av frekvensreserver för att balansera nätet, eller används det bara en typ i taget? - Vilka typer av frekvensreglering används mest/har ni störst behov av?
- När det uppstår störningar i frekvensen, är det bara ett visst område som påverkas, eller är det hela elnätet som blir påverkat?
- På er hemsida står det “Frekvensstabiliteten är gemensam för hela det nordiska kraftsystemet.”- Innebär det att man även frekvensreglerar tillsammans eller sköter varje land sig själva? Kan störningar i ett annat nordiskt land påverka frekvensen på elnätet i Sverige? - Vad är skillnaden på effektreglering och frekvensreglering?

Intermittent energi

- Hur påverkar den intermittenta energin behovet av frekvensreglering idag? - Hur tror ni att behovet kommer se ut om 5 år?
- Hur tror ni att behovet kommer se ut om 10 år?
- Är behovet av frekvensreglering på grund av intermittent energi säsongsbaserat? - Varierar behovet av frekvensreglering på grund av intermittent energi över dygnets timmar? - Vilka andra faktorer skapar behov för frekvensreglering?
- Hur tror ni att detta kommer utvecklas under de kommande 5 till 10 åren?

Balansmarknaden

- Kan vem som helst sälja frekvens på balansmarknaden? (Dvs det måste inte vara en elnätsägare eller ett energiföretag?)
- Vad finns det för krav på en leverantör av frekvensreserver?
- Fungerar balansansvar likadant för frekvens som för kapacitet?
- Som vi har förstått det kommer rollen som balansansvarig delas upp i två delar (BSP och BRP), när kommer detta ske?

Intervjuguide 5

- What were the drivers behind installing the battery?
- What are the advantages with a battery connected to a solar park?
- What is the battery connected to the solar park used for?
    - If it is used for support services, which and why?
    - Are there any drawbacks or challenges with the current use of the battery?
- What other potential areas of use can you see for the battery in the future?
- What should be taken into consideration regarding an investment in solar parks with large batteries?
- How does the current use of the battery affect the life-span of the battery?

Intervjuguide 6, 8 och 10

Elektrifiering

- Hur många tunga fordon har ni totalt?
- Har ni även lätta lastbilar?
- Är det ni som äger lastbilarna som används i er verksamhet?
- Har ni börjat elektrifiera er fordonsflotta, och isåfall, i hur stor utsträckning?
- Hur såg ni på beslutet att investera i elektrifiering, och hur ser ni på framtida investeringar?
    - Vilka drivkrafter påverkar elektrifieringen av er fordonsflotta?
    - Vilka hinder finns det för elektrifiering av er fordonsflotta?
    - Skulle potentiella ytterligare intäktsströmmar från elektrifiering i form av stödtjänster till elnätet kunna påverka ett investeringsbeslut?
- Hur ser laddmönstret ut för era elektriska fordon? Var och när laddas de?
    - Hur stor andel av tiden som fordonen laddat sker detta på er site, och hur stor andel av tiden laddas de på annan plats?
- Hur ser laddinfrastrkturen ut på er site?
    - Vad har ni för kapacitet idag?
    - Fanns det tillräcklig kapacitet från det befintliga elnätet eller har ni behövt bygga ut något?
    - Finns det tillräcklig kapacitet från infrastrukturen för vidare elektrifiering?
    -

Verksamheten

- Hur påverkas er verksamhet av krav på reducerade utsläpp?
- Har ni några samarbeten med andra aktörer kopplat till elektrifiering?

Logistik

- Hur långt i förväg planeras det var en lastbil kommer vara vid en viss tidpunkt?
  - Hålls planeringen alltid, eller kan den ändras med kort varsel?
- Hur sker ruttplanering för elektrifierade fordon? Skiljer det sig från ruttplanering för resten av fordonsflottan?
- Ungefär hur lång tid står era lastbilar i depå? När på dygnet?

Intervjuguide 7

Elektrifiering

- Hur långt har Göteborgs hamn kommit i sin elektrifiering?
- Hur ser det ut jämfört med andra hamnar i Sverige/Europa?
- Vad är det främst som driver elektrifieringen framåt?
- Vad finns det för styrmedel på en nationell och EU-nivå när det kommer till elektrifiering av hamnar och sjöfart?
- Vad finns det för fördelar och nackdelar med ökad elektrifiering i hamn?
- Vilka områden/delar av hamnens verksamheter är det främst som elektrifieras? - Vad finns det för svårigheter/hinder med ökad elektrifiering?

- Går det elektriska fartyg från och till Göteborgs hamn?
- Vilken typ av båtar är det främst som elektrifieras/passar att elektrifieras?
- Finns det begränsningar i hur många elektrifierade fartyg ni kan ta emot i hamnen?
- Vilka aktörer driver elektrifieringen av hamnen, och hur samordnas alla berörda aktörer?
- Vilka framtidsutsikter ser du för olika sorters drivmedel inom sjötransport?

Logistik

- Hur långt i förväg planeras hamnens logistik (tex vilka fartyg som kommer in, när de får lägga till, och när de lastas av osv)?
- Hur mycket påverkar elektrifiering av en hamn dess logistik?

Infrastruktur

- Finns det laddinfrastruktur idag så att lastbilar kan laddas i hamnen?
- Finns det laddinfrastruktur idag så att båtar kan laddas i hamnen?
- Finns det kapacitet från elnätet för vidare elektrifiering eller skulle

det behöva byggas ut?

- Hur ser ni isåfall på en sådan investering?
- Hur ser ni på framtida behov av laddmöjligheter i hamnen, i samband med ökad elektrifiering grad av tunga fordon?
- Finns det extra batterier för att stödja hamnen eller laddinfrastrukturen?
  - Om inte:
  - Har ni haft behov av, eller funderat på en sådan investering?

Intervjuguide 9 och 11

Elektrifiering

- Hur långt har ni kommit med elektrifieringen av lätta lastbilar, samt tunga fordon? - Vilka är era största utmaningar i samband med elektrifieringen?
- För vilka sträckor (längd och karaktär) passar el som drivmedel i tunga fordon bäst? - Vilka sträckor och körmönster passar el som drivmedel mindre bra för, och vilka drivmedel passar då bättre?
- Har ni modeller för tung fjärrtransport?
    - Om ja:
        - Hur långt kommer en sådan lastbil på en laddning?
    - Om nej:
        - Är sådana modeller under utveckling?
        - Kollar ni på alternativa drivmedel eller lösningar för tung fjärrtransport? - Vilka är de största hindrena idag?

Potentiella frågor om bussar

- Vad är likt och vad skiljer sig mellan elektrifiering av bussar och lastbilar? - Hur långt har elektrifieringen av bussar kommit?
- Vilka sträckor kör elbussar främst?
- Hur tror du att framtiden ser ut för olika miljövänliga bussar? Vilka drivmedel kommer va mest intressanta, och för vilka sträckor och typer av rutter kommer de passa?

Vehicle-to-grid (V2G)

- Hur ser ni på vehicle to grid idag? Har ni i dagsläget några fordon där V2G är möjligt? - Om nej: Vad ser ni för hinder? Finns det några rent teknologiska hinder för er när det kommer till V2G, eller är det andra faktorer som spelar roll?
- Går batteriets “livslängd” under er garanti på fordonet? Hur ser ni på att batteriet används för V2G?
- Vad finns för garantier från batteritillverkarens håll?
- Vad täcker garantin för batteriet idag?

- Är det någon skillnad mellan bussar och lastbilar när det kommer till V2G? - Vad tror ni om möjligheterna för V2G i framtiden?
- Vilka fördelar / nackdelar finns det för er som fordonstillverkare i att erbjuda möjligheter för V2G?

Intervjuguide 12

- Hur arbetar ni med stödtjänster?
- Vilka stödtjänster säljer ni främst?
- Sysslar ni med frekvensreglering, och i så fall, vilka typer?
- Vilka energikällor kommer de stödtjänster som ni säljer ifrån?
- Hur används vattenkraft vid de typer av frekvensreglering som ni säljer?
- Hur hanterar ni den korta aktiveringstiden som krävs för att kunna leverera FCR-D? Är aktiveringstiden på era frekvensreserver så pass korta, eller behöver ni använda er av batterier eller liknande lösningar för att överbrygga tiden mellan den tillåtna aktiveringstiden från SVKs håll, och tiden det tar att aktivera era frekvensreserver?
- Finns det några stödtjänster som vattenkraft passar mer eller mindre bra för.
- Hur kom det sig att vattenkraft blev så dominerande på frekvensregleringsmarkanden?

Intervjuguide 13

Batterier i fordon -

-Vad är den ungefärliga livslängden på ett batteri i ett tungt fordon (buss/lastbil)?
-Vad kan förkorta eller förlänga livstiden?
-Hur ser utvecklingen för batterier ut just nu? Vad kan man vänta sig av utvecklingen framöver?

Second life

- Vad kan ett batteri användas till efter det har suttit i ett fordon?
- Hur pass dåligt är ett batteri när det anses vara förbrukat?
- Hur ser det ut med återvinning av batterier idag?
- Vad finns det för förtjänstmöjligheter i att sälja uttjänta batterier från tunga fordon?
- I vilken utsträckning används second-life batterier idag?

Stödtjänster

- Skulle ett batteri som inte längre kan användas i en lastbil/buss kunna användas för stödtjänster istället?
- Hur påverkas ett batteri av att det används till frekvensreglering?

Elektrifiering

- Vad tror du om elektrifieringen av tunga fordon framöver?
- Vilka tror du är de största hindren?

Intervjuguide 14 och 16

Elektrifiering

- Hur långt har er hamn kommit i sin elektrifiering?
- Hur ser det ut jämfört med andra hamnar i Sverige/Europa?
- Vad är det främst som driver elektrifieringen framåt?
- Vad finns det för styrmedel på en nationell och EU-nivå när det kommer till elektrifiering av hamnar och sjöfart?
- Vad finns det för fördelar och nackdelar med ökad elektrifiering i hamn?
- Vilka områden/delar av hamnens verksamheter är det främst som kan/bör elektrifieras?
- Vad finns det för svårigheter/hinder med ökad elektrifiering?
- Vilka aktörer driver elektrifieringen av hamnen, och hur samordnas alla berörda aktörer?

Logistik

- Hur långt i förväg planeras hamnens logistik (t.ex. vilka fartyg och lastbilar som kommer in, när de får lägga till, och när de lastas av osv)?
- Hur mycket påverkar elektrifiering av en hamn dess logistik?

Infrastruktur

- Finns det laddinfrastruktur idag så att lastbilar kan laddas i hamnen?
- Finns det laddinfrastruktur idag så att båtar kan laddas i hamnen?
- Har ni något ansvar gentemot åkerier och liknande att tillhandahålla infrastruktur för laddning av elektriska fordon?
- Finns det kapacitet från elnätet för vidare elektrifiering eller skulle det behöva byggas ut? - Hur ser ni isåfall på en sådan investering?
- Hur ser ni på framtida behov av laddmöjligheter i hamnen, i samband med ökad elektrifieringsgrad av tunga fordon?

- Finns det extra batterier för att stödja hamnen eller energiinfrastrukturen?
    - Om inte:
    - Har ni haft behov av, eller funderat på en sådan investering?

Intervjuguide 15

Elektrifiering av godsleveranser

- Har ni börjat elektrifiera era godsleveranser? Hur långt har ni kommit i så fall?
- Har ni egna lastbilar eller hyrs leverans in från externa aktörer?
- Vad innebär ert samarbete kring elektrifiering med Volvo?
- Vi har förstått att ni gjort någon typ av kalkyl och optimering av rutter för hur elektriska lastbilar ska köras, hur gick det till och vad är viktigt att tänka på?
- Hur ser Ica på investeringar i elektriska lastbilar och transporter?
- Hur ser Ica på investeringar i egen laddinfrastruktur?
- Hur ser de elektriska lastbilarnas kör- och laddmönster ut?
- Finns det laddare för tung elektrisk trafik hos er? Vilken typ av laddare isåfall?
- Kostar det mer att i dagsläget leverera gods med elektriska lastbilar? - Om ja: vem tar den extra kostnaden?
- Hur tror du att kostnaden för elektrifierad transport kommer utvecklas framöver?
- Vad tror du om framtiden för elektrifierad godslogistik hos er?

Logistik

- Hur långt i förväg planeras godsleveranser?
- Planeras godsleveranser och rutter av er eller av ett externt åkeri?
- Hur lång tid brukar en lastbil i snitt stå vid av- och pålastning?
- Hur många lastbilar kör för Ica i snitt en dag

Intervjuguide 17

Elektrifiering

- Vad ser du för drivkrafter för elektrifiering av tung transport?
- Vad ser du för hinder och möjligheter för elektrifieringen?
- Vad anser du om den laddinfrastruktur som finns tillgänglig idag?
- Vem har idag, och vem kommer ha ansvaret för laddinfrastruktur framöver?
- Hur jobbar ni för ökad elektrifiering?
- Hur snabbt tror du skiftet från fossila bränslen till förnybara kommer gå?
- Hur tror du att roller inom branschen kommer förändras framöver?
- Ger elektrifieringen av transportsektorn utrymme för nya roller och aktörer på marknaden?
- Finns det några sådana som vi kan se redan idag?

Körmönster

- Hur tror du att körmönster kommer påverkas av en ökad elektrifiering?
- Vilka beteendeförändringar krävs och vilka tror du vi kommer se i samband med skiftet från fossila bränslen till elektrifierade fordon?
- Hur tror du att framtidens laddmönster kommer se ut för elektriska lastbilar?
- Tror du det kommer uppstå en problematik i att många kommer vilja ladda vid samma tider?

Vehicle to grid

- Vad tror du om framtida möjligheter för V2G med tunga elektriska lastbilar och bussar?
- Vad finns det för hinder idag?
- Vad skulle kunna driva utvecklingen inom området framåt?

End of life och second life för batterier

- Hur ser andrahandsmarknaden för elektrifierade tunga fordon ut?

- Vad händer idag med förbrukade fordonsbatterier?
- Vad tror du kommer hända med dem i framtiden?

Intervjuguide 18

Elektrifiering

- Hur många bussar har ni totalt?
- Är det ni som äger alla bussar som används i er verksamhet?
- Har ni börjat elektrifiera er fordonsflotta, och i så fall, i hur stor utsträckning?
- Hur såg ni på beslutet att investera i elektrifiering, och hur ser ni på framtida investeringar?
    - Vilka drivkrafter påverkar elektrifieringen av er fordonsflotta?
    - Vilka hinder finns det för elektrifiering av er fordonsflotta?
- Hur ser laddmönstret ut för era elektriska bussar? Var och när laddas de?
    - Hur stor andel av tiden som fordonen laddar sker detta på era siter, och hur stor andel av tiden laddas de på annan plats?
- Hur ser laddinfrastrukturen ut på era sites?
    - Vad har ni för kapacitet idag?
    - Fanns det tillräcklig kapacitet från det befintliga elnätet eller har ni behövt bygga ut något?
    - Finns det tillräcklig kapacitet från infrastrukturen för vidare elektrifiering?

Verksamheten

- Hur fungerar er verksamhet, kör ni enbart i kollektivtrafik eller även för privata aktörer?
- Hur påverkas er verksamhet av krav på reducerade utsläpp?

Logistik

- Hur långt i förväg planeras det vart en buss kommer vara vid en viss tidpunkt? Kör samma buss alltid samma rutt eller ändras det?
    - Hålls planeringen alltid, eller kan den ändras med kort varsel?

- Hur sker ruttplanering för elektrifierade fordon? Skiljer det sig från ruttplanering för resten av fordonsflottan?
- Ungefär hur lång tid står era bussar i depå? När på dygnet?