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Facilitating the transition to electrified road transports in Västra Götaland

A study on the barriers and enablers of the transition to electric trucks

SEEX30

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Gothenburg, Sweden 2020

Master's thesis 2020:NN

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Abstract

In order to achieve the ambitious sustainability goals set by the Västra Götaland Region, changes in the transport sector are required. One potential way to tackle this challenge is to transition from diesel transports to electric transports. The purpose of this study is to examine the barriers and enablers for a transition to electric transports by trucks. Furthermore, this study provides recommendations of areas within the system where interventions could be beneficial. The data was gathered through interviews, literature studies, and a webinar. The findings shows that, to accelerate the transition to electric trucks, incentives for transport buyers to procure electric transport must be increased. Furthermore, communication between haulage companies and charging providers is required to coordinate investments. Moreover, it is vital to identify early adopters of electric transports that are willing to lead the transition. Finally, the role of neutral actors cannot be understated, as it is important to have an impartial party that facilitates communication and efforts between actors, as well as communication with public authorities to direct potential support initiatives.

Keywords: *Chalmers Challenge Lab, electric trucks, transportation, charging infrastructure, enabler, barrier, transition, system innovation*

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We would also like to thank the whole Challenge Lab team: John, Linnea, Johan, and Gavin, for inspiring us in the start and giving us advice when it was much needed throughout the whole process. It has also been lovely to meet the rest of the students involved in Challenge Lab and we hope that our roads will cross again. You are all fantastic people and it has been our pleasure to share this experience with you guys.

As always, we would like to thank our families and friends for the continuous support through the writing of this thesis and throughout our studies as well. We hope that all of you, no matter your background, will enjoy reading this report. With that said, it is now time for us to take a leap out from university into the real world. Thank you.

Adam Hallborg and Emil Lagergren, Gothenburg, June 2020

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1 Introduction

Due to the ambitious goals in reducing emissions from transports, both from the region and on a EU-level, there is a need to switch to more sustainable trucks. As such, there is a need for zero-emissions trucks in order to achieve the goals that have been set. This thesis investigates the phenomenon of electric trucks, both in general, and in a local context in the region of Västra Götaland. More specifically, the study aims to showcase the barriers and enablers of a transition to electric trucks as well as answering the question of how to create change within the system. As it is quite a complex multi-actor system, it is of great need to investigate the different actors together with their incentives.

1.1 How to read this thesis

This thesis is outlined as per the recommended outlining from Chalmers University of Technology. Therefore, it is advised for the reader to take a look at the *Contents* as it gives an overview of the chapters of this thesis. Each chapter is also summarized below to give the reader a hint on what to expect from each of the chapters.

Chapter 2, *Background*, aims to provide the reader with a thorough background on the matter at hand, i.e. covering domains such as climate change, goals set by public actors, current initiatives in electric trucks both from a regional and global context, which then leads to the aim and research questions that have guided the thesis. Chapter 3, *Previous literature*, seeks to give an overview in previous research that has been focused on technological innovation systems as well as systems innovation. Chapter 4, *Method*, provides the reader with an explanation and the underlying reasons for how the research process was designed. Chapter 5, *Findings*, showcases the findings from this study where it first explains the current system and then presents both barriers and enablers. Chapter 6, *Analysis*, aims to analyze the data from the findings together with guidance from the previous literature (as described in chapter 3). In this chapter, the research questions are answered to. Then, in chapter 7, *Discussion*, the main contributions of this thesis are discussed, as well as a discussion revolving around the chosen method and the implications for both research and in practice. Lastly, in chapter 8, *Conclusion*, a conclusion is made that summarizes the main findings from this thesis.

2 Background

In the background topics regarding Chalmers Challenge Lab, climate change, electromobility from both a global and domestic perspective, as well as previously identified barriers and enablers for electric trucks are presented. Finally, the research questions and limitations of this thesis are outlined.

2.1 Chalmers Challenge Lab

Chalmers Challenge Lab (CCL) is an interdisciplinary platform at Chalmers where students from different educational backgrounds gather and seek to tackle complex questions in a collaborative manner. The questions are centered around sustainability challenges in the region of Västra Götaland. Furthermore, the purpose of CCL is to work from a systems perspective, where questions that lie between stakeholders and that cannot be solved by any single actor are discussed. The focus of CCL 2020 is on questions relating to mobility and non-mobility, specifically within the context of tourism, mobility of people, and mobility of goods. Thus, CCL 2020 is an interdisciplinary and collaborative platform that tackles questions of mobility and non-mobility in the region from a multi-stakeholder and systems perspective with a focus on sustainability. The role of Chalmers Challenge Lab is summarized in figure 2.1 below.

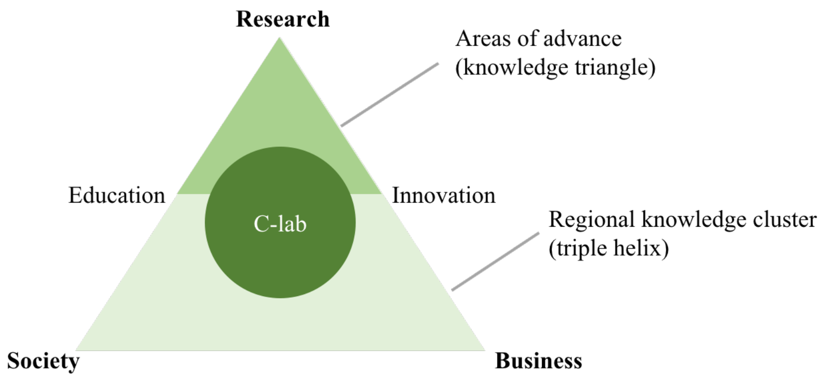

Figure 2.1: The role of Chalmers Challenge Lab

CCL is centered around the method *backcasting*, an iterative methodology developed by John Holmberg, the previous Vice President of Chalmers University of Technology as well as the program director and founder of CCL. Backcasting is split into four steps (Holmberg, 1998). The first step relates to identifying a desirable future - “How should the future of mobility and non-mobility look in the region?”. The second step involves mapping the current system - “What does the current system of mobility and non-mobility look like in the region?”. Once the first two steps have been completed, the desirable future and the current system are compared and gaps between the two are identified, and based on these gaps leverage points are formulated. Leverage points are areas of potential, where a small effort can lead to a large change in the system. Finally, in the fourth step, strategies are formulated based on the identified leverage points. The fourth step of the process is produced in the form of Master's theses, where students pair up and work on one leverage point per pair. The leverage point of this thesis is electrification of trucks, and thus the focus of the project is on the barriers and enablers of introducing electric trucks into the urban logistics in the region. The backcasting process is described in further detail in the method chapter.

2.2 Climate change and global strategies

A study carried out by the Intergovernmental Panel on Climate Change (IPCC) by request of the United Nations (UN), found that roughly 1.0°C of global warming above pre-industrial levels can be explained by human activities (IPCC, 2018). Furthermore, following the current trends, the global warming is very likely to rise to 1.5°C some time between 2030 and 2052. Global warming of 1.5°C is likely to lead to species loss and extinction, as well as risks to human safety, food and water supply, and economic growth (IPCC, 2018). Global warming beyond 1.5°C would lead to further risks to natural and human systems, such as increased ocean levels, higher temperature extremes, and increased occurrences of extreme drought. The report also found that, in order to limit global warming to 1.5°C, rapid and far-reaching transitions in human activities and systems are required. One such system that needs to adapt and reduce emissions is the transport system (IPCC, 2018).

The European Union has defined several targets to reach by 2030, including reducing greenhouse gas emissions by at least 40% compared to 1990 levels, which translates into binding targets by all member states to reduce emissions by 30% (European Commission, 2018). Roughly 25% of greenhouse gas emissions within Europe stems from transport, and transport is also the main cause of urban air pollution (European Commission, 2016). Thus, the European Union has set a goal to reduce greenhouse gas emissions caused by transport by 60% until 2050, and be on the path to zero. In order to achieve these goals, the European Commission identifies three "priority areas for action", namely improving the efficiency of transport systems, increasing the rate at which low-emission energy alternatives are deployed, and striving for zero-emission vehicles (European Commission, 2016). Furthermore, the European Commission states that local authorities and cities will play a key role in implementing strategies, which brings us to Sweden in general and Västra Götaland in particular.

2.3 Domestic and regional context

With the growth of e-commerce, and the economy in general, the transportation of goods has followed the same trajectory and has grown substantially over the last years (Västra Götalandsregionen, 2016). In Sweden in general, domestic transport is responsible for roughly one third of green house gases, and transport by road makes up 90% of the emissions from domestic transports (Trafikverket, 2019). Transport of goods make up roughly 20% of the emissions from road transports (Kloo and M. Larsson, 2019). Transportation by road is the most common option when it comes to mobility of goods, where approximately 60% of the total goods transported within the region was transported by road (Västra Götalandsregionen, 2016). At the same time, the emissions from road transports has increased by 15% compared to 1990. The number of road transports is also expected grow with 66% until 2040 (Västra Götalandsregionen, 2016). However, more efficient and environmentally friendly internal combustion engines have caused the trend of emissions to decrease somewhat. It is, however, unlikely that the emission goals will be reached as further efficiency increases will be subject to diminishing returns (Truck manufacturer representative 5 2020, webinar, 1 April). The greenhouse gas emissions from transportation by light and heavy trucks is shown in figure 2.2.

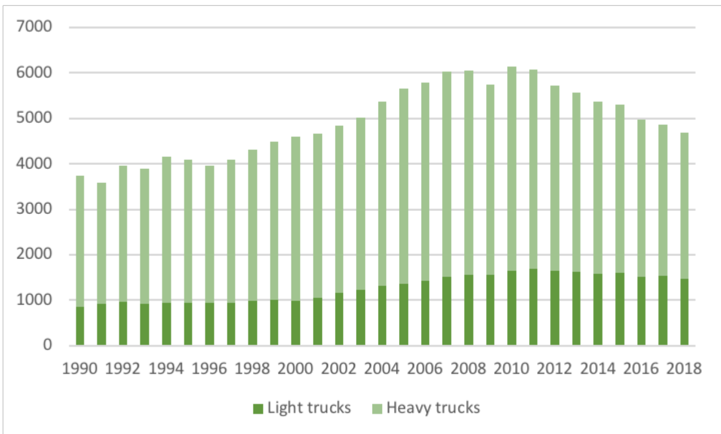

Figure 2.2: Greenhouse gas emissions from light and heavy trucks in Sweden between 1990-2018. (Naturvårdsverket, 2019)

The transports- and logistics sector in the region employs about 5% of the total labor force and it constitutes approximately 6% of the total GRP (gross region product). The companies in the region are consuming 75 million tons of goods each year and producing 74 million (Västra Götalandsregionen, 2016). Gothenburg is responsible for about 30-40% of these numbers.

The region has developed goals regarding the emissions from road transports. One of the goals is to decrease the greenhouse gas emissions by 80% in 2030 compared to the levels of 1990 (Trivector, 2019). Compared to both national and EU-level goals, the region is more ambitious in its goals with reducing emissions. The goal is also to shift the transportation infrastructure to be energy efficient and based on fossil free fuels. However, if the region follows the current trajectory in terms of emissions, this goal will not be reached. The goals of VGR's sustainable transport program can be summarized as follows (Trivector, 2019):

1. Transports within VG should be efficient and the emissions from fossil fuels decrease by transitioning to new systems.
2. Strengthened innovation capabilities within VG by fostering collaboration between industry, science, and public sector.
3. Technology and services that are developed in the region should be spread globally.
4. The need for developing, testing, and demonstrating solutions within public transport in collaboration with other actors.

With respect to the goals above, the region has developed a strategy plan in 2014 with a horizon in the year of 2020. This plan builds on the notion of *the good life*, where the region is focusing on three dimensions of sustainability: environmental, social, and economic. The region has identified several challenges connected to the three dimensions of sustainability mentioned above. In terms of environmental challenges, the report from Västra Götalandsregionen (2016) establishes that the goal of 80% less emissions in 2030 will not be met if the current trends continue. A big challenge is that the region wants less emissions, meanwhile the road transport is expected to grow quite drastically. This two-folded challenge is therefore of high interest for the region. For social challenges, the region identifies that noise and pollution are the two biggest challenges. In terms of economic challenges, the region posits that the investments in e.g. infrastructure need to be more valued by the different actors throughout the region (Västra Götalandsregionen, 2016).

On top of this strategic initiative, the region also has a climate strategy for 2030 where the goal is to have a fossil-free region in 2030. This climate strategy has six areas in which one of them is focused on sustainable transportation (Västra Götalandsregionen, 2016). Moreover, the region also highlights the need for collaboration in order to achieve the goal for 2030 that is stated in the climate strategy. In addition, in regard to the strategic plans formulated by the region, the vision is to be "*the leading transport region of the Nordics that offers efficient logistics and a transport infrastructure that supports the need of businesses and the development of the region in a way that supports sustainability and efficiency of the region as well as the improving the socioeconomics standards of the region*" (Västra Götalandsregionen, 2016).

2.3.1 RegionEl

RegionEl is a project funded by Västra Götalandsregionen (VGR), and is run by Lindholmen Science Park (LSP). It is a multi-actor project consisting of members from academia and industry, such as professors, vehicle manufacturers, and energy grid providers. The purpose of RegionEl is to provide a guide for how charging infrastructure should be deployed in the region to facilitate a faster transition to electric vehicles. Thus, this is a multi-actor initiative that seeks to bring together the incentives of different actors that are taken into account when planning, and in the future deploying, infrastructure.

2.4 The international context

Sweden, and the Västra Götaland region, are not alone in the efforts put into lowering the emissions of transport, and some global initiatives are described below.

2.4.1 Initiatives by truck manufacturers

Currently, there are several initiatives globally among the truck manufacturers in serving the market with electrified trucks. Renault launched an electric truck already in 2010, named the Renault Maxity Electric, together with the French company Tafanel which specializes in distributing beer and soft drinks all over France (Renault, 2010). Being first of its kind in a more commercial setting, the Renault had a limited range of 100 km with a maximum speed of 90 km/h. Moreover, the customer also had an option to limit the speed to 70 km/h to improve the range. The smaller size of the Renault Maxity catered to distribution in city centers. When it comes to heavy-duty trucks, Renault was also among the first of the major manufacturers to build an electric truck with early tests in commercial settings, together with e.g. Nestlé and Carrefour, between 2012 and 2016 (Renault, 2012). As a result of the previous years of testing and preparing, Renault presented, in 2018, a range of electric trucks from 3.1 to 26 tons predominantly for city use (Renault, 2018). The majority of the trucks was said to be available in the market in 2019. It should be mentioned that Renault is part of the Volvo AB Group where they share production facilities in France.

Besides attempts by Renault in the Volvo AB sphere, Volvo has also embarked on the electrification journey. In 2019, Volvo Trucks started to pilot projects that encompassed one truck each in Gothenburg (Volvo, 2019a). The first pilot project is a refuse handling truck that is fully electrified and tested by the waste management company Renova. For the second pilot project, Volvo has a distribution truck, together with DB Schenker and the local distribution company TGM, that is used for distributing goods in the Gothenburg region (Volvo, 2019a). Shortly after Volvo announced their pilot projects, they released the news that an electrification of their FL and FE lines would be offered to the market in 2020 with a production start in March of 2020 (Volvo, 2019b). These trucks are designed to mainly handle city distribution, refuse handling, among other applications within an urban context.

The Daimler AG Group have also followed Renault and Volvo in the electrification of trucks. Part of the Daimler Group is Mitsubishi Fuso which released an electric truck called eCanter in 2017 that was sold in small batches as a pilot to companies such as DHL and DB Schenker in Europe (Fuso, 2017a). These companies tested the trucks in various applications in terms of deliveries with e.g. inner-city distribution and heavy cargo. Later on, Mitsubishi announced that the eCanter would start to be produced on a larger scale in 2019 (Fuso, 2017b).

Mercedes-Benz, also part of Daimler AG, launched an electric version of their Actros line, eActros, which was delivered to ten different customers in 2018 for tests in real-world situations (Merecedes-Benz, 2018). These trucks were denoted as the *innovation fleet*. Furthermore, the eActros was divided into two variants: 18 and 25 tons, and used in mainly urban areas and traffic. Mercedes is planning to start large scale production of the eActros in 2021 (Mercedes-Benz, 2019).

Freightliner, an American subsidiary of Daimler AG, started a small pilot project with an electric truck, called the eM2, in 2018 where trucks were delivered to two different customers in California, US (Freightliner, 2019). Recently, Freightliner also introduced the eCascadia, their heavy-duty truck, to one customer for testing (Freightliner, 2019). The aim is to introduce the commercial variants of the eM2 and the eCascadia to the market in 2021.

Paccar is another group that consists of DAF and Peterbilt. DAF delivered their first electric truck, the CF Electric, in December 2018 to the Dutch supermarket chain Jumbo (DAF, 2019). Since then, the fleet has grown to 6 fully electric trucks. Consequently, DAF now proclaim that they will start to sell the CF Electric in small numbers. Peterbilt has also started an initiative in the American market towards electrification. In 2018, they released the news that they are working on electric trucks together with powertrain suppliers Meritor and TransPower (Lambert, 2018). In this partnership, Peterbilt has presented various models such as the 579EV, 520EV, and the 220EV up until 2019. Low volume production is expected to begin in late of 2020 for both the 579EV and 220EV, followed by the 520EV in 2021 (Peterbilt, 2020).

Lastly, of the big truck manufacturers, Volkswagen AG also has initiatives going on in respect to their respective brands. MAN initiated their way into the electrified trucks segment in 2018 when they allocated a limited number of electric trucks, namely the eTGM, to Porsche to use in their logistics in late 2018. Together with the collaboration with Porsche, MAN had a project together with the Austrian company CNL where they tested nine vehicles. This was then followed up by starting a small scale production series of the eTGM (MAN, 2018). MAN are planning to start their series production of the eTGM in 2022 (Electrive, 2018). Scania, who is also part of the VAG Group, has also put much effort into electric trucks, with some focus on electric roads (Scania, 2020a). It should be noted that electric roads are still using battery-powered trucks and is a way of dynamic charging throughout the trip. Scania has recently started a pilot in Oslo, Norway together with the Norwegian wholesaler ASKO where they have deployed two electric trucks in 2020 (Scania, 2020b).

Together with the initiatives from the big manufacturers, there have also been smaller players that have tried to make an entry into the field of electric trucks. In short, the car manufacturer Tesla has introduced the Tesla Semi in a press conference in 2017. The plan for Tesla is to start production by the end of 2020 (Lambert, 2019). Another entrant is the E-FORCE which was one of the earlier suppliers of electric trucks when they launched their E-FORCE ONE in Switzerland in 2013 (Kane, 2013). A third smaller player is Emoss which builds electric trucks based on regular trucks, e.g. DAF, that they convert from internal combustion engines to electric engines (Emoss, 2016). In 2012, Emoss announced its first partnership with eight other companies to deliver an electric truck in a project called *Hytruck* (Hytruck, 2015). This has then continued with smaller projects throughout the years (Emoss, 2020).

A summary of the initiatives from the main, established truck manufacturers are summarized in the timeline in figure 2.3 below. In summary, it seems that presumed truck buyers will most probably have a wide range of electric trucks to choose from as there is a plethora of on-going initiatives by truck manufacturers as of 2020.

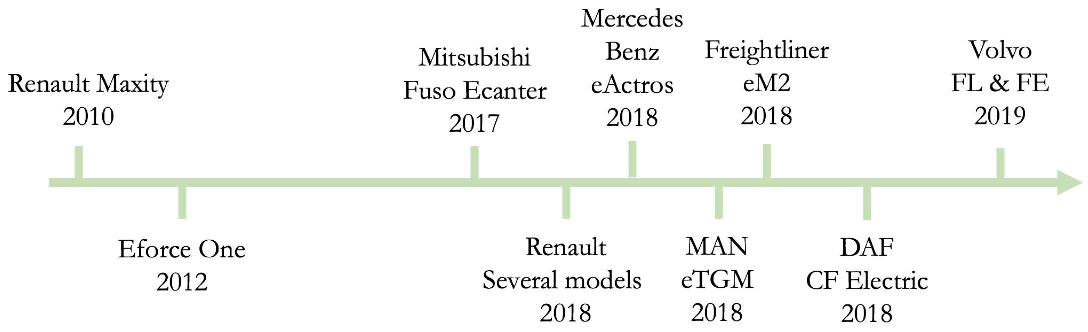

Figure 2.3: A summary of the initiatives from the large truck manufacturers

2.5 Barriers and enablers for electromobility

Several barriers and enablers for electromobility of trucks have already been identified in contemporary literature and some of these are outlined below.

Enablers

Already in the early 20th century, electric trucks existed and were prized for their reliability and strong pulling power (Heid et al., 2017). However, it has taken almost a century for truck manufacturers to seriously consider electric alternatives, and Heid et al. (2017) have found three key factors they believe will enable the transition to electric trucks. The first factor is related to the total cost of ownership (TCO), as the TCO of electric trucks is becoming comparable to that of Internal Combustion Engine Vechicles (ICEV). van den Hoed et al. (2019) calculate the TCO for both ICEV and EV. The baseline cost is 0.23 euros per km, which is representative for both ICEVs and EVs (van den Hoed et al., 2019). However, for ICEVs the majority of the cost (about 30%) comes from fuel expenditures (15% for EVs). In comparison, for EVs the main cost item is depreciation, which accounts for about 50% of the total cost. However, it is also worth to be noted that for electric trucks, the initial investment is generally bigger than for e.g. diesel trucks (Zhao, Noori, and Tatari, 2016).

For shorter distances of 100 km with delivery vans that have 30 kWh batteries, the TCO for ICEV and EV are on par with each other, where the EV is 0.02 euros more expensive per km. The interesting thing to note is that the cost for EVs decrease as the yearly driven distance increases, mainly due to the fact that electricity is cheaper per km than fuels such as diesel. As an example, with a distance of 198 km per day, the ICEV and EV will be equally expensive (van den Hoed et al., 2019). This means that even though a higher capacity battery is characterized by a higher cost, the higher cost is compensated by the low cost of electricity. Zhao, Noori, and Tatari (2016) identify that another advantage for electric motors is the low maintenance costs compared to internal combustion engines. For electric motors, there are less moving parts, less fluid, among other characteristics, compared to e.g. conventional diesel engines.

When it comes to heavy goods vehicles, there is currently a stark difference between TCO of ICEV and EV in favor of the ICEV. The ICEV is 0.22 euros per km cheaper and the reason for this, according to van den Hoed et al. (2019), is that the heavy goods vehicles are not yet manufactured in a larger scale. Additionally, the vehicle and the battery of EVs account for the majority of the costs (59%) of ownership. For ICEVs, this number is 29%.

The second factor identified by Heid et al. (2017) that will accelerate the transition to electric trucks is related to the decreased cost and increased availability of infrastructure and robust technology for EVs. Even though requirements in infrastructure represents a major challenge for the transition towards electric trucks, this challenge might not be as big for trucks as it is for e.g. electric cars. The reason for this is that the driving distances and routes of trucks are typically highly predictable and repeated (Heid et al., 2017).

The third factor is on a regulatory level, as country-wide emission targets as well as local zone restrictions are pushing towards electric trucks (Heid et al., 2017). Measures such as tightened emission targets and possible bans of diesel engines, will accelerate the transition towards electric vehicles.

Barriers
Heid et al. (2017) also identify barriers that need to be overcome for a shift to electrification to happen. These barriers include that new electric trucks need to prove their reliability; consumers, customers, and employees need to be educated and trained; and new challenges related to managing the supply chain need to be overcome.

Furthermore, Quak, Nesterova, and van Rooijen (2015) identify several weaknesses of EVs compared to ICEVs, such as higher procurement costs, lower loading capacity due to heavy batteries, and limited and unrealiable after-sales support. Moreover, haulage companies have no financial incentives to invest in EVs, as their sales will not increase as a result of a limited amount of customers willing to pay extra for environmentally friendly transports (Quak, Nesterova, and van Rooijen, 2015). Additionally, Quak, Nesterova, and van Rooijen (2015) argue that there are other uncertainties regarding electric vehicles, such as the environmental performance of vehicles using alternative fuels, and a high sensitivity to the price of energy.

2.6 Purpose and research questions

One of the two aims of this thesis is to map the barriers and enablers for the region for the transition towards electrified trucks. Therefore, the result of this thesis will predominantly focus on the actors within the ecosystem, and its respective barriers and enablers, which will act as a foundation for how to go about in transitioning into an electrification of trucks within the region. The second aim of this report is to create a strategic plan that supports the actors in moving forward, with respect to the identified barriers and enablers.

Consequently, the two research questions that guide this thesis are as follows:

- What are the barriers and enablers of the adoption and transition to electrified trucks in general and in Västra Götaland in particular?
- What key interventions could be made to speed up the transition in relation to the previously defined barriers and enablers?

2.7 Limitations

This report will not consider other alternatives to sustainable transport than electrification, however, it should be acknowledged that there are other options as well such as liquefied natural gas (LNG), but these will not be taken into consideration due to the limited time frame and focused scope of this thesis. Moreover, this report will not look into the purely operational and technical aspects of electrification, such as what kind of infrastructure that fits the needs of the region the best or questions regarding where the infrastructure should be placed. This is due to the fact that the purpose of this thesis will rather be to highlight the systematic challenges. However, this thesis will look into some barriers and enablers that inherently will be of either an operational or technical characteristic to some extent such as driving hours, driving distances, et cetera. Furthermore, the report will focus on heavy goods vehicles (those exceeding the gross combination mass of 3.5 tonnes), as electric delivery vans are already being adopted to some extent both regionally and globally. Finally, the focus of the report will lie within the context of urban transport within Gothenburg, and not on long-haul and inter-city deliveries, as the urban transports are expected to be the easiest routes to electrify. However, as all transports are somewhat interrelated, long-haul and inter-city deliveries will be mentioned.

3 Previous Literature

In this chapter, theories regarding technological innovation systems and systems innovation are presented that will be used as a lens, through which the results of the study will be observed and understood in the analysis chapter of the thesis.

3.1 Technological Innovation Systems

Bergek et al. (2008) describe technological innovation systems (TISs) as socio-technical systems that focus on the development, diffusion, and adoption of particular technologies. TISs do not only include the technology in focus, rather it includes all technologies and components that affect the spread of it. Bergek et al. (2008) highlight the need for looking at a TIS not only from a structural point of view, but also from a dynamic point of view that includes processes. They propose a scheme of analysis for analyzing a TIS, that includes six steps, as outlined below (Bergek et al., 2008):

1. The first step is to set a starting point by defining the TIS that one wants to analyze.
2. The second step involves identifying the *structural* components of the TIS, *i.e.* the actors, networks, and institutions.
3. In the third step, the focus moves from structure to *functions*, by describing what is going on in the system.
4. The fourth step is to assess the functionality of the system, as well as set process "goals" for a desired future functional pattern.
5. The fifth step includes identifying the mechanisms that can enable or hinder the evolution towards the desired functional pattern.
6. Finally, in the sixth step, specific policy issues that relates to the enablers and hinders can be specified.

The process is often not as linear and sequential as is described above, and should rather include a number of iterations between the steps (Bergek et al., 2008). Below, the six steps are described in greater detail.

Step 1: Identifying the TIS
Identifying the TIS is not always straightforward and should therefore be re-evaluated during the process. Furthermore, it is important to know how the choice of TIS affects the outcome of the study. Bergek et al. (2008) argue that there are typically three choices that must be made when identifying the TIS, namely (1) the choice between knowledge focus or product focus, (2) choosing between breadth or depth, and (3) choosing the spatial domain. Further, Bergek et al. (2008) argue that even though one can include a spatial domain to the TIS, it is vital that an international

mindset is still maintained as TISs are global in nature. The spatial component should merely function as a complement to the study.

Step 2: Identifying the structural components

In the second step, the structural components of the TIS must be identified. First, the *actors* of the system should be examined. These actors may include companies along the value chain (both up-stream and down-stream), universities, public bodies, interest organizations, venture capitalists, *et cetera*. Some methods that can be used to identify actors are (Bergek et al., 2008):

- Looking at *industry associations* to get an overview of the industry.
- A *patent analysis* can be conducted to see the activity of actors within the system.
- Conducting a *bibliometric analysis* can reveal the most active actors in terms of published papers, and will include both firms, institutes, and researchers.
- *Interviews with experts* within the industry can provide a good basis for what actors exist within the system, as well as identify further actors to contact.

After the actors have been defined, *networks* (both formal and informal) within the system must be identified (Bergek et al., 2008). Examples of networks are initiatives to solve specific tasks, and relationships between academia and industry. Informal networks may be difficult to identify and often requires discussions with experts, or analyses of e.g. co-patents or co-publications.

The third, and final, structural component is *institutions*, such as laws, norms, cultures, and regulations. Typically, the institutions must be adapted to the new technology, if the technology is to be successfully diffused (Bergek et al., 2008). When mapping institutions, a broad perspective must be taken as institutions come in many different shapes and forms, and sometimes a lack of institutions may be of interest.

Step 3: Mapping the functions of the TIS

Describing the *functional pattern* of the TIS entails describing how the system behaves based on some key processes (Bergek et al., 2008). The functional patterns of different TISs are likely different from each other, and they usually change over time. Bergek et al. (2008) propose a seven-step process for describing the functional pattern of a TIS, that consists of the following functions (Bergek et al., 2008):

1. *Knowledge development and diffusion*: This function looks at the global knowledge base of the TIS and compares it to the local performance, as well as the evolution of knowledge over time and diffusion of knowledge within the system. Different types of knowledge can be distinguished, such as production knowledge, market knowledge, and scientific knowledge.
2. *Influence on the direction of search*: This function examines the incentives and pressures for actors to enter the TIS as well as the factors that influence the direction of search within the TIS (in terms of competing technologies,

business models, etc). Examples of such factors are beliefs in the potential of growth for the TIS, actors' perceptions of different types of knowledge and technologies, regulations and policies, and demands from key customers.

3. *Entrepreneurial experimentation*: In order for a TIS to thrive, entrepreneurial experimentation is crucial, and this function is concerned with describing just that. In order to do so, the number and variety of experiments in the system need to be mapped, by e.g. looking at the number of new entrants in the TIS, the number of different types of technology, or the complementary technologies that are used.
4. *Market formation*: Markets typically go through the three different phases nursing, bridging, and mature, and this function is concerned with analyzing at what stage the TIS is in. In order to do so, one can look at e.g. market size, strategies of incumbents, and purchasing processes.
5. *Legitimation*: Legitimacy is required for new TISs to form, and is consciously created by actors within the system. Thus, this function is intended to explore the legitimacy of the TIS, the interconnectedness between legitimacy and demand, legislation, and firm behavior, as well as what or who within the TIS influences legitimacy.
6. *Resource mobilization*: This function is intended to map the resource that the TIS is able to mobilize in terms of human capital, financial capital, and complementary assets.
7. *Development of positive externalities*: Finally, the positive externalities of the TIS must be examined. Such positive externalities might be resolution of uncertainties, pooled labor markets, and specialized intermediates.

Step 4: Assessing the functionality and setting process goals
Once the dynamics of the system has been understood in the third step, these dynamics can be assessed. In order to assess how well the TIS is functioning, two complementary approaches can be taken: assessing the phase of development and comparing the TIS with other TISs (Bergek et al., 2008).

As previously mentioned, TISs go through different phases of development, and the functions of a TIS need to complement the phase that it is currently in. In order to understand whether the TIS is in a formative phase, several indicators can be examined, as outlined below (Bergek et al., 2008):

- The *time dimension* often indicates what phase a TIS is in, as the formative phase seldom lasts shorter than a decade, and, in fact, sometimes lasts several decades:
- *Uncertainties* regarding technologies, markets, and applications.
- Underdeveloped *price* and *performance* of products.
- Low diffusion and low economic activity relative to the estimated potential of the TIS.
- Unarticulated demand.
- Weak positive externalities and an absence of self-reinforcing characteristics.

By comparing the TIS in focus to other TISs, the analyst can get an understanding of the functional performance of it (Bergek et al., 2008). By comparing the functionality of similar TISs, as well as understanding what the critical functions of those TISs are, a reasonable expectation of the TIS in focus can be developed.

Step 5: Identifying enabling and blocking mechanisms of the TIS
Often, established TISs are favored and may be difficult to displace. As such, new TISs may develop slowly and have weak functional dynamics (Bergek et al., 2008). Reasons for this can partly be explained from a policy perspective, such as that proponents of the new TIS may be too weak to legitimate the system, that the potential customers of the technology may have underdeveloped capabilities, or networks may be characterized by poor connectivity between actors and thus fail to aid the new technology. There may also be enabling mechanisms, such as belief in the technology and the growth of the TIS (Bergek et al., 2008).

Step 6: Specifying key policy issues
The role of policy should be to promote the technology by reducing the blocking mechanisms and strengthening the enabling mechanisms (Bergek et al., 2008). By analyzing the weaknesses of the functionality of the TIS, key intervention points can be found where policy makers can reduce blocking mechanisms.

The article by Bergek et al. (2008) concludes that there is a need to investigate TISs in practice, by gathering empirical data from real TISs in order to revise the framework.

3.2 System Innovation

In order to tackle complex challenges such as environmental change, transformations on a multitude of different levels are required. Such transformations can be described as *system innovations*, and can loosely be defined as long-term changes in complex systems that serve a societal function (Elzen and Wieczoreck, 2005), or a shift from one socio-technical system to another (Geels, 2005). It is important to highlight that system innovation encompasses both technological change and societal/cultural change, as neither one in isolation can lead to changes towards sustainability. Furthermore, these two dimensions are interrelated and dependent upon each other (Elzen and Wieczoreck, 2005).

In order to understand system innovation, Elzen and Wieczoreck (2005) identify two key characteristics of them. The first characteristic is that system innovation occur in the *regime* of a *basic human need*, such as food, water, mobility, etc. Such regimes are composed of technologies, infrastructure, behaviors, cultural attitudes, etc. The second characteristic builds upon the first, and states that system innovations affects most or all of the dimensions of the regime. At the very least, system innovation is characterized by a combination of technological and behavioral change. In addition to the two aforementioned characteristics, system innovations typically display the following properties (Elzen and Wieczoreck, 2005):

- *Multi-actor*: System innovations involve a variety of actors, such as firms, consumers, NGOs, governments, etc;
- *Multi-factor*: System innovations cannot happen by a change in a single factor, rather a multitude of factors affecting each other must change for system innovation to take place. Such factors are typically technical, regulatory, behavioral, and societal;
- *Multi-level*: System innovations happen at different levels - the micro-level of individual actors, the meso-level of rules and regimes, and the macro-level of societal and cultural characteristics.

Geels (2005) expands on the multi-level perspective. The *meso-level* is comprised of socio-technical regimes, which include things such as the cognitive routines of engineers, manufacturing processes, and the existing knowledge base in the context of relations between social groups. The *micro-level* is made up of technological niches, which act as innovation rooms for radical innovations. Finally, the *macro-level* is the socio-technical landscape within which the transitions take place, and involves wider factors such as globalization and cultural changes. The landscape is largely given and cannot be changed by any individual actors. In order for system innovations to happen, interplay is required between the different levels (Geels, 2005).

The multiple levels at which system innovations take place indicate the complexities involved for transitions to happen. In order to achieve such complex transitions, several barriers of different nature might exist, such as regulations, infrastructure, or investments, and public authorities can play a key role in overcoming these barriers and enabling innovation (Elzen and Wieczoreck, 2005).

Regulators have different tools at their disposal that they can use to induce system innovation, such as environmental standards, taxes, and subsidies. Elzen and Wieczoreck (2005) argue that one potential shortcoming of such tools is that they are often used to realize a rather well-defined, short-term goal, which is in direct conflict with system innovations, as these are typically vaguely defined and long-term in nature. In addition to the aforementioned tools, public authorities can also act as a facilitator to induce system innovation, by e.g. hosting technical conferences and encourage collaboration (Elzen and Wieczoreck, 2005).

Geels (2005) argues that system innovations come about in different phases. The first phase is when new technologies emerge in niches within the context of the existing socio-technical regime and landscape, and this phase is characterized by high experimentation and a lack of dominant design. In the second phase, the new technologies find use in small market niches and a collective of engineers and producers surrounding the technology will emerge. During this phase, a stabilization process will occur, with regards to e.g. rules, dominant design, and user preferences. The third phase encompasses a widespread diffusion of the new technology, and competition with the existing regime. Such breakthroughs depend both on internal factors such as price and performance, but also on what Geels (2005) calls “windows of opportunity". Finally, the fourth phase is when the new technological regime replaces the old one, which often occurs over a long time.

Geels (2005) identifies two main pathways through which system innovations can come about: (1) technological substitution, and (2) wide transformation. In technological substitutions, new technologies emerge "below the surface" in an established regime, and when the technology experiences a breakthrough, incumbent actors may be taken by surprise by its diffusion, which has also been described as *disruptive innovation* by the late, great Clayton Christensen from Harvard Business School (Christensen, Raynor, and McDonald, 2015). Wide transformation is characterized by early experimentation by established actors within a regime, during which a wide variety of different technologies emerge. After an initial period of heavy experimentation, the number of technologies is narrowed down, and a particular solution may become the dominant design. Moreover, system innovations typically follow a "fit-stretch" pattern (Geels, 2005). Fit-stretch means that initially, the form and functions of new technologies have a close fit to the existing regime (the first cars were described as "horseless carriages"), but over time technological improvements lead to new forms and functionalities which stretches the existing regime, and eventually the establishment of a new socio-technical regime (Geels, 2005).

4 Method

This chapter presents the methodology that was used during the thesis. The initial step was to use backcasting as a process to arrive at a relevant research question. After that, the research was done by mainly literature studies and interviews as approaches to gather data. The gathered data was then analyzed with the help of a theoretical framework as was presented in the previous chapter. The process is presented in more detail in the sections below.

4.1 Backcasting

The leverage point of electrification of trucks was identified by the *backcasting* methodology. Backcasting is a process, consisting of four steps, whose main objective is to guide transitions towards sustainability (Holmberg, 1998). The backcasting process relies on quite a reverse type of mindset, where requirements and possibilities that sustainability will have in the future are compared to today's situation, which enables us to see the current system in a new light (Holmberg, 1998). Backcasting is divided into a four step process, where the first step is to identify a framework for sustainability encompassing the criteria that needs to be achieved in order for a system to be sustainable. In the following step, which is the second step, the current system is mapped and its components are related to the previously mentioned criteria. Based on this, in the third step the future is envisioned based on the findings in the two preceding steps. The notion of *leverage points* are important in step 3, which are the points where a small nudge or adjustment can create big change in the system. In step 4 then, strategies to bridge the gap between the current situation and the preferred future are presented. Below, the four steps in the backcasting process used for this thesis are presented in greater detail.

4.1.1 Step 1: Define a framework for sustainability

To guide step 1, the *sustainability lighthouse* by Holmberg and J. Larsson (2018) was used in order create the sustainability foundation for the future steps. The lighthouse encompasses four different sustainability perspectives: social, ecological, economic, and human needs (and well-being). As an example, in terms of social sustainability, the group of students at CCL posited that *trust* in the system and between people is vital. *Inclusion* in the system and in decision making is key. Lastly, *equality* in opportunities is an important ingredient of social sustainability. More importantly, the perspective that really guided the research question of this thesis, was the ecological perspective of sustainability. Predominately, the aspect of *maintaining a healthy environment* is crucial for ecological sustainability. As described in the background of the thesis, emission-free solutions are key in order to maintain a healthy environment and e.g. reach the goals from the UN. Moreover, the healthy environment is also important for living beings with noise pollution, where electrification of trucks comes into play.

4.1.2 Step 2: Describe the current situation based on the sustainability principles

The second step of the backcasting process was to identify and map the current system (Holmberg, 1998). In the CCL, external stakeholder dialogues, with stakeholders active within the system of study, were used in order gain insights into the intricacies of the current situation. Hence, stakeholders were invited to the CCL where discussions around the current situation took place in a participatory setting. Literature studies were also carried out during this step in order to gain an even deeper understanding of the system. The sustainability principles from the lighthouse were of use as they helped cover important aspects of sustainability, which is useful when mapping the current system.

This second step is considered to be the very foundation of both steps 3 and 4 (Holmberg, 1998). This is due to the fact that a good understanding of the current situation is needed when both finding leverage points to create change and then to formulate strategies to bridge the said gap.

4.1.3 Step 3: Identify the leverage points

When the two first steps were finished, we studied the system together with its dynamics and related these to the sustainability principles that were developed in step one. Holmberg (1998) posits that it is important to keep in mind, in this step, that the future system should not be determined in detail. Rather, one should be open-minded for different options in order to create change and contribute to a more sustainable system (Holmberg, 1998).

4.1.4 Step 4: Finding strategies for sustainability

The fourth and final step of the backcasting process is to find strategies in order to bridge the gap and strive towards a sustainable future. For this thesis, the *strategy* is related to the barriers and enablers of electric trucks in the region, where proposed strategies are based on the barriers and enablers. This thesis clearly presents the barriers hindering the system from moving towards a sustainable transition, which in turn supports the strategic plan and actions that should be taken in order to make the transition happen.

4.2 The research process

When the research question had been formulated in accordance to the backcasting process, the study was carried out in an inductive manner. This meant for the thesis that data was initially gathered and then theory was applied to provide an analytical viewpoint, or rather acting as a lens, when viewing and analyzing the results from

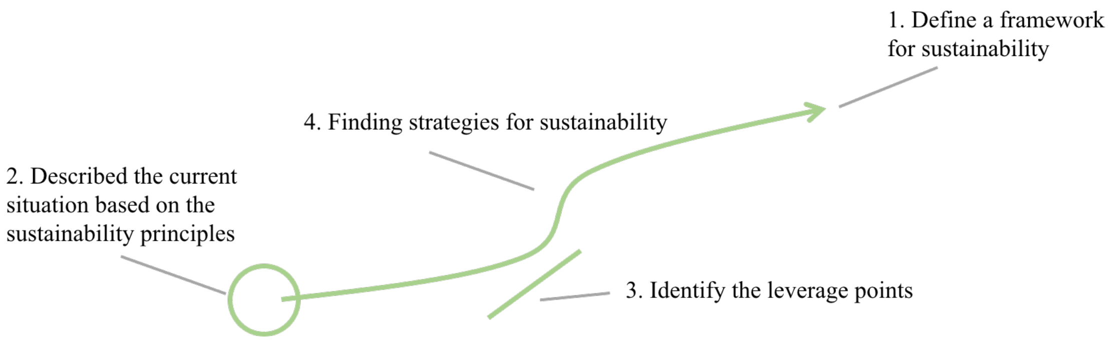

Figure 4.1: The process of backcasting

the data collection. The study was carried out by conducting several interviews in order to gather data, together with complementary literature studies to fill in the gaps of possible missing information or to explain certain phenomena in the system. Due to the covid-19 outbreak, this was useful as some interviews were canceled. Furthermore, a webinar with representatives most of the actors was held by RegionEl in which we participated. This webinar functioned as another data point as new issues and/or possibilities arose as the actors gave presentations on their view regarding electrification of trucks. Consequently, this acted as a complementary resource in the data collection of this thesis.

The data gathered from the interviews, literature studies, and the webinar, was then analyzed with the help from a theoretical framework that provided with the structure of the analysis, which is explained in more detail below. The rationale for having a theoretical foundation to base the analysis is simply to be able to view the results and help describe the relationship between certain parts or certain phenomena (Gioia, Corley, and Hamilton, 2012).

4.3 Identification of relevant literature and theories

The theory was found through an exhaustive literature review in the area of research applicable to the domain of this thesis. First and foremost, as the theory in this thesis is in the area of *system innovations*, related key words were used when searching for relevant literature. For instance, words such as *system innovations, transition, multi-level perspective, actors* among other words, were essential to have an efficient way of sourcing literature. More importantly, the use of databases for finding literature was equally as important as the key words themselves. For this thesis, two main databases were used: Chalmers Library and Google Scholar. In these databases, the literature was readily available in an interface that was easy to use.

The literature was exhaustive, which highlighted the need for an efficient way of skimming through large masses of text. According to Easterby-Smith, Thorpe, and

Jackson (2015), an efficient method is to have criteria for how to evaluate the applicability of the article at hand. In this case, the key words of articles was to much help in order to see if it fit with the scope of this thesis. Then, when the first large initial sorting of articles was done by predominately looking at the abstract of articles, the sorting of articles was done efficiently in order to find the ones that were most applicable. As a last step in making a final selection for which articles to use, the main arguments and concluding remarks of each article was presented in a summarized manner which in turn made it easier to see patterns and to determine which theoretical cornerstones that could reinforce and support the analytical viewpoints used throughout this thesis.

For the general data collection, the literature study there was done in the same manner as for the theoretical framework. The literature for the data collection have simultaneously been extracted through stakeholder meetings from which recommendations were made in regard to which literature that was appropriate for the scope of this thesis. Furthermore, articles, reports, and other sources were used. As previously mentioned, the data derived from this type of literature was used as a complement to the information gathered from interviews.

4.4 Interviews

As this study is based on a qualitative approach, interviews are one of the most common options in gathering qualitative data (Easterby-Smith, Thorpe, and Jackson, 2015). Interviews can be described as conversations focused around certain topics and domains pertaining to the aim of the study that is carried out by the researchers (Easterby-Smith, Thorpe, and Jackson, 2015). As a preemptive step in order to be well prepared for interviews and data collection, a strategy for this was set up. The reason for having such a strategy is to focus efforts on how to go about in selecting participants based on what kind of qualitative data that is needed for the study to be carried out (Easterby-Smith, Thorpe, and Jackson, 2015). For this specific case, an approach called *snowball sampling* was used. The snowball sampling approach is when selected participants help with reaching other participants from their acquaintances who possess useful information in regard to the research topic (Easterby-Smith, Thorpe, and Jackson, 2015). This approach was supported in the beginning by an *ad-hoc sampling* approach, where the researchers reached out to people in close proximity to the CCL. The reason for this approach was to gather a few important stakeholders based on ease of availability and access (Easterby-Smith, Thorpe, and Jackson, 2015).

Together with the sampling strategy, Easterby-Smith, Thorpe, and Jackson (2015) also posit that a topic guide is useful to form prior to the interviews. Consequently, a topic guide that contain the topics that are interesting in terms of the *research question* was crafted. The main topics of interest were: actors, economy, infrastructure, and barriers and enablers. The topic guide can be found in Appendix A. This guide was useful as it let the interviewers follow a structure to make sure that the important domains of the research were covered throughout the interview, while allowing flexibility at the same time. The ordering of the specific domains was not of high importance, as Easterby-Smith, Thorpe, and Jackson (2015) posit that the topic guide should merely act as a tool for structuring the information that is sought after in the interview, rather than providing a complete and rigid structure of the interview or questions asked. Easterby-Smith, Thorpe, and Jackson (2015) put forward the importance of relating the questions to the interview subjects in order to make sure that questions posed are understood in a correct manner. This was done by researching both the organization and the interviewee that was next in line to be interviewed. Consequently, the research about the interview subject helped in many ways, e.g. by relating the questions to the role of the interview subject. By continuously doing this, the questions could be developed further but were still kept within the previously mentioned areas in the topic guide.

The questions asked during the interviews were framed in such a way that they promoted open-ended answers, which is of importance when gathering qualitative data from interviews (Easterby-Smith, Thorpe, and Jackson, 2015). In order to achieve this, the questions were carefully worded and continuously examined in order to ensure that they would provide to the topic relevant answers. As such, the questions were formed to be easy to understand and comprehend - meaning that theoretical concepts and other intricate wordings were left out in interview settings (Easterby-Smith, Thorpe, and Jackson, 2015).

The notion of interviews encompasses a lot of different techniques and methods, which can be selected based on what the researcher wants to achieve. For this report, with a limited time span, the most efficient way to gain useful insights while being effective time-wise was to use semi-structured interviews. In short, according to Easterby-Smith, Thorpe, and Jackson (2015), semi-structured interviews are organized in a way that lets the interviewee(s) and interviewer(s) focus on a selection of topics or domains that are covered in the interview. This is especially beneficial when the objective is to let the interviewee freely express its insights in a time-effective manner (Easterby-Smith, Thorpe, and Jackson, 2015). As previously described, the topics that were present in the interviews were developed in the topic guide. By having a set of topics, the conversation could then unfold in relation to where the interviewee goes but at the same time allow the interviewer to steer the direction of the interview in relation to the topics (Longhurst, 2010).

In total, 10 interviews with 11 interviewees were conducted. The domains of the topic guide were covered in every interview, although specific questions relating to the unique insights of the interviewee were also asked to get more in-depth with the specific intricacies pertaining to that role in the ecosystem of electric trucks. However, these were asked after the initial questions of a specific topic had been dealt with. These types of questions are what Easterby-Smith, Thorpe, and Jackson (2015) denote as *probes*. Probes are used to get a deeper understanding of the *real* reasons to e.g. why a respondent answered in a specific way or to make certain insights clearer. There are several options when it comes to probing such as returning to the initial question when the interviewee is off track, focused probes to gain more in-depth information, silent probe in order to let the interviewee have time to think through the answer, and mirroring insights from the interviewee is also a good probe in order to let him or her rethink the answer previously given (Easterby-Smith, Thorpe, and Jackson, 2015). These types of probes were used throughout the interviews when they were necessary. In other words, the more general questions were good bases for supporting the conversations and steering the direction of it, while the in-depth questions were asked as a concluding remark whenever one of the topics had been considered finished with.

4.4.1 Interview structure

The interviews were to a large extent conducted face to face with physical meetings that usually took place at the workplace of the interviewee. This was found useful in order to find time slots that fitted into the busy schedule of the interviewees, which deemed the researchers to be flexible both spatially and temporarily when booking interviews. For those occasions when the interviewees were located far outside Gothenburg, the interviews were performed by the help of Skype. As the researchers were two in total, one was main responsible for asking questions and facilitating the interview, and the other one responsible for taking notes. These roles were occasionally switched up between the pair, in order to gain useful insights and experience in both roles.

The lion's share of the interviews were recorded. The rationale for this was to have the option to go back to the interview and revisit specific sections of the interview that could have been unclear among other reasons that deemed a revisit to be necessary. Another benefit with recording the interview is to give the note-taker some space to make mistakes and not feel the pressure to include everything said during the interview. This also helps with the gathered data to be less prone to biases from the interpretation of the interviewers, as the recordings showcase the exact information put forward by the interview subject (Easterby-Smith, Thorpe, and Jackson, 2015). However, a drawback with recorded interviews is that the interview subject might feel inclined to phrase the answers in a certain way due to the awareness of being recorded, which could cause some information to be left out. With the help of having semi-structured questions regarding specific areas, the notes could easily be fitted into each of the areas during note-taking. This provided us with structured notes all across the interviews.

4.4.2 Interview subjects

In total, 10 interviews with 11 interview subjects were held, where one of the interviews was held with two participants. Below, the interviewees are presented, however for the sake of anonymity their names are not disclosed. Instead, the interviewees are categorized depending on their role in the ecosystem. A description of their role is also provided.

1. Expert 1 - Involved in projects relating to questions of mobility and transporta-

tion within the Gothenburg region, working at a municipality-owned company.
2. Expert 2 - Researcher with a focus on sustainability issues, with experience in working with the transition towards electric buses in the Gothenburg region.
3. Expert 3 - Representative from the municipality's office, working with questions relating to mobility and transportation within the Gothenburg region.
4. Expert 4 - Researcher at one of Sweden's leading universities with a focus on electromobility in general, and charging solutions in particular.
5. Expert 5 - Project manager at a research platform in Gothenburg, with a focus on electrification of mobility.
6. Expert 6 - Assistant project manager at a research platform in Gothenburg, with a focus on electrification of mobility.
7. Truck manufacturer representative 1 - Product owner at a large, established truck manufacturer with a responsibility for charging components on electric trucks.
8. Truck manufacturer representative 2 - Manager at a large, established truck manufacturer, with a responsibility for charging solutions regarding electric trucks.
9. Truck manufacturer representative 3 - Senior project manager with a focus on electromobility at a large, established truck manufacturer.
10. Truck manufacturer representative 4 - Senior project manager of sustainability and responsible for roll-out of electric trucks to the Swedish market at a large, established truck manufacturer.
11. Energy grid representative 1 - Senior project manager at an energy grid company.

In addition to the literature study and interviews, data has been gathered from a webinar that was organized by RegionEl. A list of attendees that presented at the webinar can be found below, along with a description of the contents of their presentation. A description of the attendees' role is also given unless they have already been mentioned in the list above.

1. Expert 4, 5, & 6 - Presented a result of a data collection regarding charging infrastructure.
2. Truck manufacturer representative 2 - Gave a presentation on their future offerings in the electric truck segment, as well as how to use data from trucks to aid the transition to electric trucks.
3. Truck manufacturer representative 5 - Working with public affairs at a large, established truck manufacturer. Gave a presentation of electrification in general, as well as specifics regarding how to use truck data to facilitate a transition towards electrification. In addition, an overview of future offerings in the electric truck segment was given.
4. Public agencies representative 1 - Senior advisor at the energy department. Gave a presentation on the role of public actors in the transition to electric trucks.
5. Public agencies representative 2 - Official at the environmental protection agency. Gave a presentation on the role of public actors in the transition

to electric trucks.

6. Expert 4 - Gave a presentation regarding the cost structure of using electric trucks, and when it is cost efficient to use electric trucks.
7. Haulage company representative 1 - Strategist at a sewage & recycling company. Gave a presentation of their experience of using an electric truck in their daily practices.
8. Haulage commpany representative 2 - CEO of a haulage company. Gave a presentation of their experience of using an electric truck in their daily practices.
9. Energy grid representative 1 - Gave a presentation about their role in the transition to electric trucks.
10. Energy grid representative 2 - Business developer at an energy company. Gave a presentation about their role in the transition to electric trucks.
11. Energy grid representative 3 - Product owner at an energy company. Gave a presentation about their role in the transition to electric trucks.
12. Petrol station representative 1 - Product manager at a petrol station chain. Gave a presentation about their role in the transition to electric trucks.
13. Petrol station representative 2 - Real estate developer at a petrol station chain. Gave a presentation about their role in the transition to electric trucks.

4.4.3 Analysis of data

The data was analyzed by the help of a theoretical framework in a three step process that has been inspired by and adapted from the work of Bergek et al. (2008), which has been described in the previous chapter. The first step was to analyze the initial mapping of actors and their barriers and enablers in order to create a prioritization of the collected data and to get an overview of the most critical issues within the system. Based on this first step, the second step was to relate the barriers and enablers between the actors and develop the system's map with the relations between actors to create a more dynamic view of the system. Then, the third and final step was to look into the gridlocks in the current system and identify, together with the previously identified enablers, the most essential keys to unlock the inert situation and create system-wide change, i.e. accelerating the transition. In order to structure the findings, six thematic areas were developed that statements were categorized as. The thematic areas were developed from a pragmatic viewpoint, where common denominators that frequently surfaced in the data collection acted as the basis for the presentation of the findings. These six categories were: demand-side, regulatory, financial, organizational, technical, and attitude.

Step 1: Analyze the actors

Based on the findings, the first step of the analysis was to map out the individual barriers and enablers for each of the actors together with the initial system's mapping from the findings that provided the basis for which actors that are involved in the system. By doing this, the mapping of the system was developed to increase the depth.

Furthermore, as a way to prioritize between the statements from the actors, the number of actors that had made the same type of statements was calculated. This calculation laid the foundation for how the prioritization was made, as the more numbers of actors saying the same thing increased the priority of that category of statements. In the end, this provided an overview of the most critical issues for each of the actors for which to ground the rest of the analysis on.

Step 2: Relate the actors with each other

The second step in the analysis was to relate the barriers and enablers from each actor to others within the system. Here, the categorization from the previous step was used as a way to group statements from different actors together, which allowed for similarities and differences between actors to be identified. Consequently, the mapping of actors was further developed to encompass the relations in terms of the barriers and enablers, as well as to create connections between the actors. From this, key crucial leverage points in the system were identified for which strategies were developed in the third step.

In this part of the analysis, the theoretical framework was used to give nuance and guide the viewpoints. Thus, there is a strong connection between the design of the analysis process and the theoretical framework, meaning that this process was grounded in previous literature.

Step 3: Accelerate the transition

The third and final step in the analysis was to look into the relations in the system's map and from that identify how to resolve the critical points that were the root causes of the inertia. From these very root causes, a strategic plan was developed that seek to find the keys to unlock the current inert situation. The strategic plan was developed by inductive reasoning, based on the previous steps in the analysis.

Figure 4.2: The analysis process of this thesis

5 Findings

In this chapter, the findings from the data collection are presented. First, the current system is mapped in order to set the boundaries for the barriers and enablers. Second, the barriers and enablers from the data collection are presented.

5.1 The current system

From the interviews, a mapping of the actors pertaining to the electrification of trucks has been developed. Below, the identified actors are presented as well as the number of interviewees that highlighted them as a key actors in the transition:

Table 5.1: Key actors involved in the transition to electric trucks, number of interviewees that mentioned said actors, and the total number of interviews conducted

Actor	# mentions (*n=10*)
Haulage companies	8
Power grid companies	7
Public actors	7
Charging providers	6
Vehicle manufacturers	6
Transport buyers	4
Property owners	2
Freight forwarders	1

The actors are presented in layers based on involvement in the transition towards electric trucks. In the innermost layer, the actors that are directly responsible for the transition are located. In the outer layer, actors that have a supporting or enabling role are located.

In the innermost layer, we find the haulage companies, charging operators, and truck manufacturers. The logic behind locating these three actors in this layer is based on the findings of the interviews. The interviews showed that (1) haulage companies are directly responsible for the transition to electric trucks as they are the ones who purchase and operate the trucks, (2) charging operators are directly responsible for the transition to electric trucks as they are the ones who operate the charging infrastructure that is necessary to charge and thus operate electric trucks, and (3) truck manufacturers are directly responsible for the transition to electric trucks as they are the ones who develop, manufacture, and sell them.

In the outside layer the remaining five actors are located, based on the findings of the interviews. The interviews highlighted that (1) transport buyers' role in the transition towards electric truck is to encourage haulage companies by e.g. being willing to pay a premium for electric transports, (2) the power grid companies' role is to ensure power supply to allow charging providers to offer the necessary charging stations, (3) public actors' role is to encourage a transition by e.g. putting demands on transport buyers to favor electric transports, or subsidizing haulage companies that purchase electric trucks, (4) property owners' role is to allow charging providers to build charging stations on their premises, and (5) freight forwarders' role is to encourage transport buyers to purchase transports from haulage companies that use electric vehicles, i.e. the transports are not carried out by freight forwarders but by haulage companies. However, there are some instances where freight forwarders have their own in-house haulage company. Another actor that was mentioned by several interviewees was power companies, however in this thesis they will be treated the same as power grid companies. The system's mapping in all its glory is summarized in figure 5.1 below.

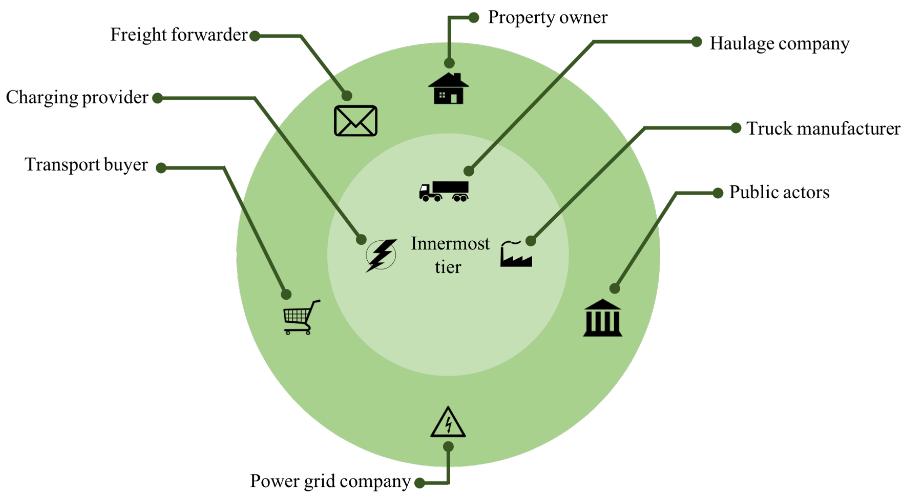

Figure 5.1: The two tiers of actors in the electric trucks' system

5.2 Enablers

Below, the enablers that were identified in the interviews are presented. They are grouped according to the six thematic areas: attitude, demand-side, financial, organizational, regulatory, and technical.

5.2.1 Attitude

Statements that were grouped under the thematic area of *attitude* were related to how different actors feel regarding electric vehicles, the knowledge they possess regarding electric trucks, and the way their behavior has changed or needs to change in the future. A statement made by four interviewees was that they want to share knowledge in order to accelerate the transition towards electric trucks. This is highlighted by the following quote made by a representative from a truck manufacturer:

> *We will act as advisors regarding infrastructure for at-home charging, depot charging. Possibly also financiers of the system in the long run. [...] We want to help and contribute with the competency and knowledge that we possess regarding the vehicles, their range, and battery performance, and so forth, because there is nobody else that really knows this stuff. So in some way, we act like the spider in the web.*
>
> *- Truck manufacturer representative 3*

Another common statement, made by a majority of the truck manufacturers, was that they have to, or have already started to, adapt their sales processes to assume a more consultative role towards their customers. This is highlighted in the quotes below:

> *We have developed a sales program, where we sit down with clients and look at the routes of the trucks they want to electrify, and we look at how far they drive, what they carry, and so forth. And you do a fairly basic simulation, looking at, for example if the truck drives between Borås, Alingsås, and Gothenburg, you look at if the truck you are specifying can complete that route with four batteries, or if you have to charge it somewhere along the way.*
>
> *- Truck manufacturer representative 3*

> *Much more will be required of the sales organization to sell these [electric] vehicles, and that is the case for all new technology. [...] Regarding electric propulsion you also have to help the customer to look at what type of routes and how to plan routes so you get the repetitive pattern, as well as identify what types of routes are possible to electrify, which is a big difference compared to other renewable fuels, and we have to work a lot on that.*
>
> *- Truck manufacturer representative 4*

Another enabler is to showcase other actors that driving electrically is feasible, where these can inspire the other actors. Especially, the state or municipality can take the lead in this regard and be early in electric trucks to showcase both for haulage companies and other actors that it works. This was highlighted by one of the truck manufacturers:

> *By cities going into the lead to showcase [...] is really an enabler to start the transition [...] and show that the trucks that they are purchasing are electric which can make other actors test as well [...] - and their trucks are often very visible as they are in operation in areas with people which increases the attention in marketing electric trucks.*
>
> *- Truck manufacturer representative 4*

Moreover, the working environment of drivers is improved when driving electrified trucks as compared to conventional alternatives, according to haulage company representatives. Below, a quote by one of the haulage company representatives highlights this improvement made possible by electric trucks:

> *The drivers [...] are very positive, a few things they have said are that they are not as tired in the evenings after working with this [electric] truck compared to a diesel truck. They also said that you get to know your colleagues better, you become more social because you can talk to each other when sitting in the truck and when walking around the truck.*
>
> *- Haulage company representative 2*

5.2.2 Demand-side

For the demand-side, statements are concentrated on describing the actors that are on the demand-side of the system, i.e. actors such as transport buyers that can be both public and private actors. One statement that reoccurred in four of the interviews was the fact that transport buyers play a crucial role in making the transition to electric trucks happen. The transport buyers were regarded as important due to their ability to e.g. pay more for sustainable transport or put requirements on the haulage companies to use transport solutions such as electric trucks. This was highlighted by one of the experts in the following quote:

> *It really is a buyer's market where the transport buyers put requirements on the haulage companies and easily switch between different companies and for the transition to happen the transport buyers might need to provide longer contracts to give haulage companies more security and less financial risk [...], which also might take the form of requirements from haulage companies to have longer contracts or financial compensation for more expensive, albeit sustainable, trucks.*
>
> *- Expert 4*

Moreover, the public actors were especially noted as a possible actor to start with. The reason for why public actors are good to start with is due to several reasons. One reason is that public actors could be change leaders in sustainability, where they could seek to set a new standard for transports. This opportunity was highlighted by one of the experts, which said that procurement-wide requirements could pave the way forward in supporting the transition:

> *In municipal procurement, there is a great opportunity to have requirements on electric trucks or other environmental requirements such as zero emissions, where the same could go for the state or counties in their procurement.*
>
> *- Expert 1*

Another reason is that public actors, such as national agencies, usually do not compete on the same terms as private actors. Therefore, there is a stronger likelihood that public actors are both able and willing to pay more for their transports in order to enable transition. A third reason, as highlighted in the interviews, is that public actors are usually large transport buyers, e.g. healthcare institutions, which then have stronger mandates to create change and increase awareness that could spread to other sectors and industries as well.

The public opinion is also regarded as an important factor when it comes to the electrification of trucks. By having efforts that try to increase the awareness among companies in general and by that persuading a shift in the mindset of the companies in what it entails to switch to more sustainable transports. However, in the end, the transport buyer is ultimately the actor who needs to pay more for sustainable transports:

> *Due to the low margins of haulage companies, they will need to increase the prices to compensate for sustainable transports. [...] In the end, it is us end customers that need to see and understand the value of sustainable transports.*
>
> *- Truck manufacturer 4*

5.2.3 Financial

Several financial enablers were identified in the interviews. For instance, the length of the contract that the haulage company has with their transport buyers and the level of trust between them plays a big role in enabling their purchasing power. Haulage companies that have long contracts have a more predictable financial situation and are therefore able to make investments with a longer pay-off time, such as electric trucks. One interviewee stated the following when asked whether any haulage companies are able to take the step towards electric vehicles without external help:

> *It is my impression that some of the [haulage companies] that we have talked to are a little more confident that they are able to take this step themselves, however these are typically companies that have found a niche where they are so good at what they do that they have no real competition, and therefore they do not really compete on price. [...] An example of such a company had specialized on emergency deliveries of medical supplies, and they were so good at it that they had built a lasting relationship of trust and longer contracts with their buyers.*
>
> *- Expert 4*

Another financial enabler that was identified in the interviews is that electric trucks are cheaper to operate than conventional trucks, as the price for electricity is lower than that of diesel. Furthermore, electric vehicles typically require less maintenance than alternatives, as there are fewer moving parts than in an internal combustion engine, which contributes to the lower operational cost.

> *An enabler is the lower marginal cost per driven kilometer. That is where the entire business case lies at the end of the day. The kilometer cost must be cheaper for the [electric] vehicles you buy because for the foreseeable future, electric vehicles will be more expensive than diesel vehicles.*
> *- Truck manufacturer representative 1*

There is also a financial incentive for property owners to invest in charging stations, which therefore is a financial enabler. The logic behind this statement is that there are likely synergistic effects for many businesses between having charging stations at the same location as they have e.g. a shop or a restaurant, as customers who stop to re-charge their batteries are likely to also stop to buy something from the store, such as lunch. The logic behind this statement is outlined in the quote below, from one of the expert interviews:

> *It is very likely that there will be publicly available quick-chargers at strategic locations that a lot of haulage companies can use to gain some flexibility and complement their charging. [...] It is fairly likely that, at such "truck stops", the person that owns restaurants and other businesses at the truck stop, or the property owner perhaps, is the one who has the greatest synergies of coordinating and making sure that there are chargers there - not only to make money of the charging but also to increase revenue to other businesses at the truck stop. In such a scenario one could imagine that it would be difficult for somebody who only owns chargers to make as much profit as somebody who owns both the chargers and the entire property. And in such a scenario it is fairly likely that it is the property owner who wants the charger and who is willing to make the investment, and also make most of the profit. It might even be the case that the property owner makes calculations that show that they run the chargers at a loss, yet still think that it is a good idea.*
> *- Expert 4*

5.2.4 Organizational

In terms of enablers in the organizational part of the system, one of the more prominent enablers from the interviewees was the fact that the state, and other public actors, could take on the role of being responsible for the public charging infrastructure. As was found in some of the interviews, this would solve the issue of the chicken and the egg problem, due to the current inertia being created by the uncertainty regarding whether electric trucks or charging infrastructure should be in place first. Consequently, by having the public actors taking the role of providing charging infrastructure to some extent, this would increase the likelihood of the transition to happen in a not too distant future as it gives a clearer direction of the future with electrified trucks, as stated by the same group of interviewees.

Another enabler that was mentioned in the interviews was the possibility of having the public sector doing its own transports in a sustainable way. Being quite reminiscent with public actors paving the way as a transport buyer, they could also be in the frontier when it comes to performing the transports sustainably. An example of this kind of initiative is the *Stadsleveransen* which is a project within the Gothenburg city area where the Traffic Office Department together with the Gothenburg city offer transports to e.g. stores in the city center. According to one of the expert interviews, this could be a golden opportunity for projects like Stadsleveransen to take on a leading role in the transition towards electrified trucks.

> *The city is looking into whether they can buy products without buying transport, so that they handle the transports themselves. Then, you could govern all transport that the city buys, and since this is such a big volume they might be able to save money on transports, [...] and put demands on for example electrified vehicles.*
>
> *- Expert 1*

From an organizational point of view, the state could also play a crucial role in coordinating the deployment of infrastructure. One of the experts pointed to the fact that a coordinating role might be necessary in order to ensure an infrastructure that is both demanded and strategically placed in order to support the transition. Therefore, coordination is an important factor that can act as a catalyst in having infrastructure in places that are good from both a strategic and geographical point of view.

5.2.5 Regulatory

When it comes to regulatory enablers, one of the most common statements made by all interviewees was that subsidies and policies that can support truck purchasing are important to transition towards electric trucks. Nine of the eleven interviewees stressed that haulage companies typically have low margins and therefore low ability to invest in electric trucks unless the business case improves. Several different examples of policies and subsidies were suggested, such as subsidies for haulage companies that invest in electric trucks, environmental zones that only electric trucks may enter either permanently or during certain hours, as well as increased incentives for transport buyers to invest in the more expensive environmentally friendly transports, such as taxation of fossil transports. One of the interviewees expressed this in the following way:

> *Laws and regulations could help support this transition somehow. [...] Whips and carrots can help. One could imagine some sort of experiment with fees and taxes, or limiting access to certain roads, or during certain times, there are a lot of things you could do. [...] Initially, public funds could perhaps be used to support those who buy electric trucks.*

- Expert 1

Another regulatory enabler is that the current regulatory system for professional drivers fits rather well with electric trucks. This was highlighted by two interviewees, who stated that drivers are only allowed to drive for four hours and thirty minutes straight before they need to take a break, and, assuming infrastructure is in place, drivers can charge their vehicles during this break to provide them with battery power for the rest of the day.

Moreover, for truck manufacturers there is a risk for fines if they do not meet environmental regulatory standards which pushes them in the direction towards electric trucks. In turn, this creates motivation for the truck manufacturers to start developing more sustainable trucks that conforms to e.g. emission requirements. One of the truck manufacturers stated that the directives from EU are something that affects a large part of their markets, which in turn causes them to shift focus into e.g. electric trucks.

5.2.6 Technical

For the technical side, one of the most prominent enablers that was acclaimed by several of the interviewees, especially by the experts, was the need for strategically placed infrastructure in terms of charging stations. This was said to be of great importance, as the limited range of an electric truck can be complemented by having charging infrastructure placed in locations that is within close proximity to usual routes. Moreover, the strategically placed infrastructure does also play a role in the psychological domain of enablers, as having a set infrastructure will help the haulage companies feel more secure in terms of investing in electric trucks.

Urban transports have been considered a low hanging fruit when it comes to electrified trucks, as several interviewees pointed out the fact that they are characterized by comparatively shorter distances and pre-defined distribution routes. Coupled to this enabler is the fact that haulage companies generally have the same routes each year. As such, there a few characteristics in urban transports that make them especially good as an entry point for electrification:

> *There are two reasons that make urban distribution suited for electric trucks; the first one is that their distances are not too long, which means that they do not need a large battery capacity; and the second reason is that urban transport companies drive repetitively so it is easier to plan in order to make it fit with the charging infrastructure that is at hand.*
>
> *- Expert 4*

From a technical standpoint, this means that it is easier to optimize the battery capacity which in turn optimizes the price for the electric truck for haulage companies as they do not need to pay for excess capacity. Conversely, today's technology is regarded as "good enough" for urban transports as current batteries have enough capacity to cover the general demand from urban transports. This also entails that the need for public charging infrastructure is less due to the shorter distances. The recent testings of electric trucks in the region have proven to work reliably, which have showcased that electric trucks are a possibility with today's technology. The right battery size is more important than a large battery size, which the following quote highlights:

> *A common misconception is that people tend to think that a larger battery capacity solves the problem, rather than thinking about the economically correct solution that is to be smarter and more knowledgeable about what capacities that are needed to avoid driving around with a battery that is not used to its full extent.*
>
> *- Expert 4*

At the same time, a larger battery size gives comfort to the haulage companies, however it is associated with a much larger cost. Consequently, for haulage companies to feel safe, there is a likelihood that it will come at a large cost. This dilemma is showcased in the quote below:

> *It will always feel safe to have enough capacity to know that one will always be able to make all future scenarios on the battery's capacity, which feels safe, but it is ultimately too expensive.*
>
> *- Expert 4*

Connected to the current goals of EU, the current internal combustion engines (ICE) are becoming increasingly more difficult to make more efficient in terms of emissions, according to one of the truck manufacturers. In other words, the development of ICE is characterized by diminishing returns, meaning that the more effort that is put in developing better, streamlined engines, the less rewards can be reaped in terms of emissions. Therefore, this is something that intrinsically supports the shift to electrification. Moreover, the current development is rapid and the truck manufacturers consider themselves to make good progress where serial production is about to start as of 2020. For the development, the truck manufacturers are also piggy-backing on the development in the car industry.

5.3 Barriers

Below, the enablers that were identified in the interviews are presented. They are grouped according to the six thematic areas: attitude, demand-side, financial, organizational, regulatory, and technical.

5.3.1 Attitude

Statements that were grouped under the thematic area of *attitude* were related to how different actors feel regarding electric vehicles, the knowledge they possess regarding electric trucks, and the way their behavior has changed or needs to change in the future. A statement made by four interviewees was that there is a need to spread knowledge of electric trucks in the system, relating to e.g. the capabilities and possibilities of electric trucks, as there are a lot of misunderstandings. This is highlighted by the following quote made by an interviewee:

> *The industry needs to learn and understand this. [...] To understand how to think when dimensioning a vehicle. In our discussions with haulage companies, they have been very interested and relatively well-read [...] but there are certain basic things that have been misunderstood. [...] For example, one client had missed that the efficiency of an electric engine is 90-95%, while on a diesel engine the efficiency is around 30-40%. So they had calculated the energy required to convert an entire fleet of cars in their terminal, and used a factor that was off by two to three times.*
> *- Truck manufacturer representative 3*

Another barrier that was brought up by two of the experts was that even though haulage companies are generally positive to change, they often do not want to be early adopters of the technology. Rather, they often prefer to see that other actors, such as their competitors, switch to the new technology to provide them with a sense of security that the new technology is the right choice.

> *The trucks sector would benefit from having success stories like Tesla in the car industry to showcase that it actually works.*
> *- Expert 4*

5.3.2 Demand-side

One of the more prominent barriers when it comes to transports is that sustainability is ranked lower in comparison to e.g. transport accuracy and price from the perspective of transport buyers. Consequently, there are lack of incentives when it comes to prioritizing sustainability as there are other factors that are deemed more important.

> *If one looks into the future, there are a couple of things that will take some time. If one looks at the price [...], if the truck costs about four times as much as a conventional distribution truck [...] my experience tells me that nobody wants to pay more, or at least haven't wanted to pay more in the past, just because we drive a more expensive truck. Before prices reach an acceptable level, it will be difficult to find somebody who is willing to pay that much more just because we drive an electric truck*
> *- Haulage company representative 2*

Overall, according to several of the interviewees, the transport buyers do generally have a low willingness to pay (WTP). As described above, transportation of goods could generally be described as a commodity, meaning that demand-side actors view transports as a small part of their procurement. In turn, there could be other factors that are prioritized before transportation and especially in the cases where electrified transportation generates higher prices, which has been highlighted by several interviewees. Furthermore, below, a quote from a report from the Swedish Association for Road Transport Companies highlights that consumers in general do not want to pay more for electric transports, and that cost efficiency is a barrier for electric trucks.

> *Cost efficiency is important and is weighed against the reduction of greenhouse gas emissions, which is why the argument for a long time has been that a battery driven truck struggles to compete with a diesel truck with today's technology. This perspective could be changed if society's demand for fossil free transports shift, and a willingness to include idle time in the price of transport could therefore change the view that battery driven trucks do not work in heavy traffic.*
>
> *(Sveriges Åkeriföretag, 2019)*

5.3.3 Financial

A financial barrier that was brought up by four interviewees is that haulage companies in general have very tight margins, as highlighted by the following quote:

> *[The haulage industry] has very low entry barriers: you need a driver's license, a YKB-permit, a cheap old truck for ten to fifteen thousand SEK, and then you are up and running, and because of this there are a lot of small haulage companies. [...] Haulage companies in general have tight margins. The cost structure is very transparent: a truck costs this much, maintenance this much, tires, drivers, and so on, so the buyers know just as well as the seller what the cost is, which presses margins tremendously. The low barriers to entry also creates fierce competition which further squeezes the margins.*
>
> *- Expert 1*

This barrier is further exacerbated by the fact that the investment costs of electric trucks are higher than for diesel, as highlighted by three interviewees, which is illustrated in the following quote:

> *The prices have to go down in many segments. This is true for both trucks and personal vehicles, but especially for trucks, it is way too expensive to buy an electric truck right now. [...] It is quite unfortunate that they are so expensive right now, because that makes it too expensive for anybody to take the leader jersey and say "Now I'm going to get ahead of my competition". So the price is definitely an issue right now, [...]*
>
> *- Expert 4*

Moreover, three of the interviewees brought up the fact that haulage companies often have short contracts with their transport buyers which reduces certainty regarding driving routes and income. Long-term uncertainty regarding contracts creates a financial barrier as the haulage company might be hesitant to make large investments with long payback time. The problem of short contracts is highlighted by the following quote:

> *Small haulage companies often have short contracts [with their transport buyers], and that is a problem. It is a buyer's market, they can set demands and obviously it is good for them to never commit to long-term contracts, in order to switch [transport supplier] and squeeze prices all the time. But this is a problem for the transition of the industry, because it means that those who own the trucks don't have any margins to take any financial risks whatsoever. So, [the haulage companies] will most likely either demand longer contracts or some sort of guaranteed remuneration if they are to switch to more expensive vehicles. That is the sad backside of the situation.*
>
> *- Expert 4*

Another financial barrier, that was brought up by one of the experts, relates to the residual value of trucks. For diesel trucks, the residual value is well-known and decent, which makes an investment into a diesel truck less risky. For electric trucks, on the other hand, the residual value is not known which creates uncertainty regarding the return on investment (RoI) for haulage companies. In other words, the haulage companies prefers to be as much risk averse as possible.

5.3.4 Organizational

The issue of the chicken and the egg problem has been discussed in many sectors throughout history, and according to a lion's share of the interviewees, that same problem is present within the system of electrified trucks. This has taken the form of a struggle between infrastructure on the one hand and trucks on the other, where the issue lies in the intricacies of when and where infrastructure should be deployed and if infrastructure should be deployed before trucks. Inherently, there is a great deal of uncertainty, as actors who want to make investments with as low risks as possible want to have a current demand, i.e. electric trucks, before making large investments in infrastructure. On the other hand, a similar pattern is found among those who are intended customers to electric trucks, where they are more inclined to purchase an electric truck if there is a public charging infrastructure, to some extent at least, in place. This would relieve some of the risks with making their investments, in the same manner as electric trucks mitigate the risks for charging providers in terms of their investments. In this case, the system cannot rely on the VGR to make investments for infrastructure, as they, according to one of the experts, are not focused on being part of a market but rather focus on small pilot projects and not system-wide infrastructure.

Perhaps tightly coupled to the barrier described above, there is a need for wide collaboration in order to make the transition happen. Not only in terms of the clash between infrastructure and trucks, but also in terms of e.g. financing and regulation. Inherently, this involves a lot of different actors that need to work in a collaborative manner. The interviewee mentioned that working in cross-collaboration across many different actors require an alignment of incentives in order to have a fruitful transition for all actors involved. Thus, aligning the incentives among many actors is a barrier in the transition towards electric trucks. This has for instance been prominent in the energy sector, where the energy companies need to have a continuous dialogue with different actors to plan for the future, in other words the need for collaboration is strong in that regard as well.

> *We have dialogues continuously, [...] it is tremendously important that Volvo, for instance, have enough electricity to be able to produce and develop electric cars [...] because we cannot just say that there is not enough electricity to cover the demand.*
>
> *- Energy grid representative 1*

Currently the system is characterized by an unclear division of roles, where this has one of its most presence in the issue of financing and the question of who should be responsible for carrying out the investments necessary. A majority of the interviewees have mentioned that the haulage companies are expected to be responsible for making investments in terminal charging and electric trucks. However, one expert stated that it might make more sense for property owners to invest in depot charging, since most haulage companies rent their facilities. Two of the expert interviews have pointed towards the fact that there is a need for collective investments which in turn requires collaboration between different types of actors that previously have not been present in the conventional truck sphere.

Moreover, the ownership of charging infrastructure is also in a state of ambiguity, as there are unclear roles there as well. Energy companies have shown interest in investing in infrastructure, but at the same time there are charging providers in the electric car market that might be interested in offering truck charging as well. As the roles have not yet been set in who should be responsible for what, it increases the uncertainty in the system as a whole. For terminal charging, this has also been an issue with unclear roles as most haulage companies do not own their facilities, which in turn causes their incentives to invest in charging infrastructure to be much lower:

> *To have a charging infrastructure on a facility that one does not own is not beneficial once one decides to move, which then leads to that depot charging becomes a question for the property owner and they have not realized the value of this yet.*
>
> *- Expert 4*

There is also a difficulty when it comes to the different lead times that actors have. For instance, a power grid line takes approximately ten years to build, and during that time a lot of development has undergone in the trucks sector. Consequently, there is a hinder to align these different lead times to make the system efficient.

> *Let's take the example of data centers, which take two years to build, but the power chord does not come in seven years, and all of a sudden there is a mismatch. [...] Without margins in the power grid network then one cannot just connect another node into the power grid network.*
>
> *- Energy grid representative 1*

5.3.5 Regulatory

Regulatory barriers did not come up in most of the interviewees, however haulage companies did raise some concerns. First of all, they mentioned that environmental zones might not be the right way to go, as they would increase costs for haulage companies since they would have to driver longer distances to reach their destination. If transport buyers are not willing to pay for this increased cost, environmental zones would only be a negative for haulage companies. One representative from a haulage company put it the following way:

> *Environmental zones are, well, that's the whip. Deciding that certain areas should be electric only for example. And that raises the question of how that is going to be paid, because that means a higher cost for the businesses in that zone - hotels, restaurants, shops, offices, and so on - which is a big challenge.*
>
> *- Haulage company representative 2*

Another regulatory barrier that was identified is that haulage companies have some uncertainty regarding the long-term price stability of electricity. There is a view that, as consumption of diesel decreases, tax revenue from that source diminishes. This could likely lead to increased taxation of electricity and thus increased prices. Therefore, the lower operational costs of electric trucks compared to conventional trucks might not be stable long-term if regulations change, which is a barrier for haulage companies to invest in electric trucks. Below, a quote from a representative from a haulage company illustrates this:

> *The price for electricity that we have today, is what we have today. I mean, the state must collect tax money, and I can't imagine that they can be without the tax money that they make on fuel tax today. Instead, other types of road taxes and other types of taxes will probably emerge to compensate for the loss of fuel tax from the state. So I don't think that one can rely on the price that we have on electricity today. It's going to be much more expensive. I am convinced of that.*
>
> *- Haulage company representative 2*

5.3.6 Technical

In terms of technical barriers, when it comes to electric grids, the management of power is an important factor as charging is expected to put increased pressure on the current infrastructure. Therefore, there will be a need for managing the usage of electricity in order to cope with the current capacity. This might hinder flexibility, as charging for instance might have to a large extent occur over night with lower power. Nonetheless, the coordination when it comes to usage of power is essential in order to not run out of power. This is quite a new situation that the energy sector, and other actors, find themselves in as the following quote suggests to juxtapose the current situation with what was previously:

> *It has always worked in a calm environment [...] regardless if you had built a school, a factory, or a new house, you just had to make an order for a new connection to solve it [...] up until a few years ago when it became clear that power actually can run out [...] which really was an awakening.*
>
> *- Energy grid representative 1*

The issue of what type of energy source that will support the development in the energy infrastructure is also crucial. If the electrification is supported solely by coal plants, then the environmental gain is dispersed, according to one of the energy grid representatives. Alas, the development of infrastructure needs to be aligned with the supply of green energy sources in order to not compensate the new infrastructure with unsustainable energy sources, according to a representative from an energy grid company. At the same time, there is a need for flexibility in when to charge to not strain the power grid network, which means that charging overnight with low power is beneficial for the infrastructure to not have any power spikes during other times of the day and to even out the power demand.

> *There will be a question of steering the power outtakes of the infrastructure, for instance charging, [...] to charge as much as possible with low power during a longer time period [...], so a lot of these types of situations will appear to use the grid in a good manner and to mitigate the power spikes to have an even load on the grid.*
>
> *- Energy grid representative 1*

In this regard, quick charging might be troublesome to implement in the Gothenburg city. As an example, Tesla's quick charger for their Tesla Semi has supposedly a 1 MW capacity. For the Gothenburg city, the total capacity for the whole grid is 800 MW which then covers the demand of electricity for the whole city. Therefore, the energy grid company representative stated that currently there are no possibilities to have such high capacity quick chargers because it is not supported by the energy infrastructure.

To gain an economically sound usage of electric trucks, there is a need to maximize its usage. This is putting larger pressure on the haulage companies to maximize the usage of their fleet of electric trucks. Moreover, there is a strong likelihood that the battery capacity will be over-dimensioned in the beginning to mitigate the risks of how the battery will develop for future usage and to have space to be more flexible. In other words, there is likely that an excess capacity will be needed in the beginning to have a buffer. Inherently, this will carry additional costs which in turn might hinder the adoption of electric trucks due to the investment threshold that it creates. One reason for this is that haulage companies, with conventional trucks, have been able to be very flexible in their business:

> *Today [...], the users of trucks have been spoiled by being able to use their trucks in a very flexible manner to drive different routes, and for electric trucks [...] a repetitive driving pattern is key to gain an economic benefit from it.*
>
> *- Truck manufacturer representative 4*

As stated in the quote above, the issue of flexibility is more prominent for electric trucks compared to conventional trucks. As the electric trucks carry a limited capacity with them, it could hinder the flexibility for the haulage companies to not be able to accept extra jobs. This is a factor that could steer them away from electric trucks. Consequently, this highlights another hinder in that electric trucks require quite rigorous planning in order to work efficiently compared to conventional trucks.

For public charging infrastructure, there is an issue that the deployment of infrastructure is needed in order to reach a system-wide adoption as one interviewee has pointed out. Therefore, there is a need for having an infrastructure set in order to support a wider adoption of electric trucks. Then again, this is denoted as the chicken and the egg problem and is further described in the section about *Organizational* barriers above.

6 | Analysis

In the following chapter, the findings that was presented in the previous chapter will be analyzed. The analysis consists of three steps, namely analyzing the mapping of enablers and barriers, relating the barriers and enablers to others within the system, and finding the key intervention points within the system to increase the speed of the transition. The analysis has been inspired by Bergek et al. (2008)'s work on technological innovation systems (TISs). Furthermore, the relationship between the findings and the theories developed by Geels (2005) and Elzen and Wieczoreck (2005) is explored, to show that the transition can be characterized as a systems innovation. Lastly, an identification in which phase of the process the transition is currently in, is made.

6.1 Mapping enablers and barriers

The TIS has been identified as electric trucks in the Gothenburg region with a complementary international context. The structural components of the system includes the actors (Bergek et al., 2008). The actors that have been found were presented in the findings, and are repeated below:

- Haulage companies
- Truck manufacturers
- Charging provider
- Power grid companies
- Public actors
- Transport buyers
- Property owners
- Freight forwarders

Below, the enablers and barriers that the different actors have expressed from their points of view are presented. Furthermore, enablers and barriers that actors have expressed regarding other actors are shown. This analysis is based on the fifth step of Bergek et al. (2008)'s methodology, which is to identify mechanisms that can enable or hinder the evolution towards the desired functional pattern. Moreover, steps three and four of Bergek et al. (2008)'s methodology has inspired the process through which the enablers and barriers have been identified.

6.1.1 Haulage companies

First, the enablers are presented, and second the barriers. Both statements made by haulage companies and statements made by other actors regarding haulage companies are included.

Enablers for haulage companies

The only financial enabler that could be identified for haulage companies is that the marginal cost per driven kilometer is lower than for diesel trucks. This can be explained by the lower price of electricity as compared to diesel, as well as lower expected maintenance costs for electric trucks due to fewer moving engine parts. However, it should be noted that haulage companies have expressed concerns regarding the long-term price stability of electricity, which will be discussed below.

Regarding the technical feasibility of electric trucks, the haulage companies are relatively positive as testing has shown that the electric trucks work as reliably as diesel trucks. Both of the haulage company representatives that had tested electric trucks were happy with the results as the trucks were able to perform the activities they were required to. However, it should be noted that these test trucks typically had to re-charge during the middle of the day, and that the routes that they drove were planned so that they could be performed by a battery-driven truck. This indicates that there are still some technical mounds to overcome, such as making sure that drivers plan their lunch breaks to happen at charging stations, and the increased requirement for route planning for haulage companies. These barriers will be explored further below.

An enabler that was identified regarding the attitude towards electric trucks is that the work environment for drivers significantly improves when driving electric trucks as compared to diesel trucks. The reason for this is that the cabins are much quieter. Furthermore, one of the tested trucks is a garbage disposal truck, and drivers that work with such trucks usually keep the engine running when walking around the truck to collect garbage. Therefore, the work environment is significantly improved for drivers of garbage disposal trucks not only when inside the cabin, but also when working outside the truck as well. A consequence of this, is that electric trucks could help haulage companies attract drivers. This could be considered an enabler for haulage companies to transition to electric trucks, as there is a shortage of truck drivers in Sweden currently, and many haulage companies have trouble recruiting. Thus, for companies that want to recruit new drivers, investing in electric trucks could be a way to do so.

Related to the aforementioned enablers of lower marginal cost and using electric trucks to attract new drivers, is the positive effects of utilizing electric trucks as much as possible in order to achieve cost efficiency. Even though electric trucks have a much higher investment cost, higher cost efficiency can still be reached when compared to diesel trucks, if the utilization rate is high enough and the battery capacity is properly dimensioned. Haulage companies ideally want to utilize their trucks as much as possible by driving them in shifts, so that the same truck is driven by two drivers every day, to minimize idle time. However, in order to achieve this, the hours during which customers can receive goods need to be expanded. Currently, most haulage companies are not able to utilize their trucks in shifts, as the hours during which customers can receive goods are typically covered by one shift. Furthermore, the aforementioned lack of drivers inhibits the ability to utilize trucks in shifts, as there might not be enough drivers employed at the company to cover multiple shifts. Moreover, grid companies have stressed how important it is for charging of trucks to be spread over a long time period with low power. If electric trucks were to be utilized in two shifts of nine hours each, that would only leave six hours of charging which would require higher power than if only one shift is utilized, and therefore the grid capacity is another barrier for higher utilization of trucks. Thus, an enabler for electric trucks is the ability to utilize them in shifts, however several barriers currently stand in the way for this to happen.

Another enabler that was identified was that haulage companies are generally very positive to change. Contrary to what one might initially believe, the hauling industry is not conservative and reluctant to change, rather they welcome changes and want to help accelerate the transition to more environmentally-friendly trucks.

Moreover, an enabler that has been identified is the need to identify what haulage companies can be early adopters of electric trucks. Many actors have highlighted that a lot of haulage companies do not have the financial resources to invest in electric trucks. This is mainly due to the low margins that the haulage industry is characterized by, but also the fact that most haulage companies have short contracts with their transport buyers. However, some key actors have been identified as the exceptions that confirm this rule. Firstly, haulage companies that have contracts with public actors, such as garbage disposal services, can be early adopters as they have more long-term security regarding their contracts with their buyers. Moreover, they are subject to public procurement, which means that the public can put requirements of environmentally friendly transports in the procurement process. Secondly, niche actors that have specialized in certain areas and consequently differentiated themselves on their ability to deliver niche solutions in that area, are more likely to be early adopters. This is because they are subject to less competition than typical haulage companies and have longer contracts with their buyers, meaning the risk of procuring the more expensive electric trucks is reduced.

Another enabler that was identified relates to the role of subsidies to support haulage companies that invest in electric trucks. As mentioned above, haulage companies have small margins, and as was shown in the result, electric trucks are currently too expensive for most haulage companies to invest in them. Thus, a majority of the actors have highlighted that there is a need to have a subsidy-system in place that encourages haulage companies to invest in electric trucks. Currently, "Klimatklivet" is a subsidy-system that encourages investments in, among other other things, electric vehicles and their charging infrastructure. However, Klimatklivet is a subsidy that support *investments*, which means that companies applying for Klimatklivet needs to procure whatever it is that they want help financing. This presents a barrier, as many haulage companies do not directly invest in new trucks, rather they utilize leasing solutions to minimize financial risk. Currently, Klimatklivet does not subsidize leasing solutions, which therefore is a barrier for the widespread adoption of electric trucks. It should be noted, however, that solutions to these problems are currently being looked into, and Klimatklivet will likely be reworked to also subsidize leasing solutions. In table 6.1, the identified enablers for haulage companies are summarized.

Table 6.1: Identified enablers for haulage companies

Enablers	**Explanation**
Lower marginal cost	The price of electricity is lower than the price of diesel, and the maintenance cost for electric trucks should be lower
Technical feasibility	Tests have shown positive results regarding the technical feasibility of electric trucks, however some small hurdles still need to be overcome
Work environment	Electric trucks have a positive impact on the work environment of drivers, as the cabin and area around the trucks are quieter
Maximize utilization	In order to achieve cost efficiency, a high utilization rate of electric trucks is required by driving trucks in shifts
Positive attitude	In general, haulage companies are positive to change and willing to contribute to the transition to electric trucks
Early adopters	Early adopters of electric trucks are likely to be those who have public actors as customers, as well as niche actors that are subject to less competition
Subsidies	Subsidies will likely play a large role in encouraging haulage companies to invest in electric trucks, and current subsidy systems need to (and likely will) adapt to also include subsidies for leasing solutions

Barriers for haulage companies

Several barriers have been identified for the adoption of electric trucks from the haulage companies' perspective. As indicated above, the financial situation presents a barrier for most haulage companies. The findings showed that the haulage industry is characterized by low barriers of entry, which leads to high competition and low margins for haulage companies. Consequently, a majority of haulage companies do not possess the financial means to invest in electric trucks, which presents a barrier for the wide-spread adoption of electric trucks.

Moreover, the high degree of competition creates a situation where it is very easy for transport buyers to switch their suppliers for transports. As shown in the results, the market for transports is characterized as a buyer's market, where the buyer sets the demands and typically only commit to short contracts as they want flexibility to be able to switch suppliers as they please. The trend of short contracts creates a problem for haulage companies, as long-term investments become riskier if there are uncertainties regarding the revenue streams that will be gained during the period that the investments is expected to be paid off. Additionally, short contracts likely mean that there is less predictability of long-term driving patterns of the haulage companies' truck fleet. Having a high degree of predictability and repetitiveness of driving routes is a key factor to make electric trucks technically feasible and cost efficient. Therefore, the impact that short contracts have on driving patterns also present a barrier.

Relating to the aforementioned barriers of low margins and short contracts, is the fact that electric trucks are currently significantly more expensive that diesel trucks. The underdeveloped and high price of electric trucks is an indication that the TIS is still in its formative phase, as described by (Bergek et al., 2008). Because of the underdeveloped prices, many haulage companies are unable to invest in them, and are likely waiting for prices to decline before they make any investments. This creates a problematic situation, as prices will only start to decline once economies of scale starts kicking in as a consequence of increasing volume. However, volumes will not increase unless investments happen, and this situation can thus be characterized as a catch 22 - volumes will not increase unless prices decline, but prices will not decline unless volumes increase.

As was mentioned previously, there is currently a shortage of drivers in the haulage industry. This presents a barrier for electric trucks for a few reasons. First, haulage companies can likely not be as selective when hiring new drivers as they want to, which consequently might lead to the hiring of drivers that are less skilled than what would be ideal. Driving electric trucks puts additional requirements on drivers, as a skilled driver will be able to squeeze more kilometers out of a battery than an unskilled driver, due to driving style. Thus, having less skilled drivers can provide a barrier as the technical feasibility of the electric trucks can be lowered if they are not driven correctly. Second, as mentioned previously in the "Enablers"-section, a shortage of drivers means that it is more difficult for haulage companies to utilize trucks in shifts. This is a barrier as a high degree of utilization is vital to achieve cost efficiency of trucks.

Relating to the aforementioned requirement of high utilization of trucks, is the narrowness of the time windows during which transport buyers are able to receive goods. Ideally, haulage companies want to utilize their trucks as much as possible, however since transport buyers are only able to receive goods during certain hours, it does not make much sense to operate trucks during hours when their customers can not receive the deliveries. Thus, the operational efficiency of trucks is inhibited by the time windows during which customers can receive goods, which presents a barrier for the adoption of electric trucks.

Another potential barrier is the fact that the load capacity is lower for electric trucks than diesel trucks, as the batteries are heavy. This means that the weight that any hauler can deliver with an electric truck is lower than it is for a diesel truck. However, this does not present a problem for all haulage companies, as the limiting factor for a lot of transports is the volume rather than the weight.

Furthermore, in order for electric trucks to be technically feasible, a high degree of predictability and repetitiveness of driving patterns is required. For most haulage companies, this is not a problem for the majority of their transports as they typically have similar driving patterns from day to day. However, sometimes situations arise where the haulage company diverts from the predictable driving pattern, to make a special transport. In such cases, a high degree of flexibility is desired for haulage companies to fulfill their customer's needs. The requirement for such flexibility could be a barrier for the adoption of electric trucks, as electric trucks are less flexible than diesel alternatives due to the limited driving range. To overcome this challenge, a wide-spread roll-out of charging infrastructure is essential to make haulage companies feel confident that they can perform unique and flexible transports even though they are driving electric trucks.

Another barrier that has been identified is that there is a lack of knowledge among haulage companies of electric trucks. For example, as was shown in the findings, some haulage companies are not aware of the efficiency of an electric engine compared to a diesel engine, and thus make calculations of energy requirements based on faulty premises. Another common misunderstanding is related to the price of public charging, as many haulage companies might be reluctant to charge at public charging stations as they are more expensive. However, a basic calculation of the cost structure shows that public charging can actually be quite expensive and still be cost efficient, as it reduces the need for a large battery and thus creates a lower investment cost of the truck. This could create a situation where some haulage companies are reluctant to invest in electric trucks simply due to misunderstandings of the technology.

Table 6.2: Identified barriers for haulage companies

Barrier	**Explanation**
Low margins	Low entry barriers leads to high competition, causing many haulage companies to operate on small margins, leading to a situation where most haulage companies can not afford to invest in electric trucks
Short contracts	The transport industry is a buyer's market, where most transport buyers only commit to short contracts with haulage companies, which creates uncertainty regarding the haulage companies' future revenue streams and driving routes
High price of eTrucks	Electric trucks are significantly more expensive compared to diesel trucks at the moment, which is a major barrier for widespread adoption when combined with aforementioned financial barriers
Shortage of drivers	High utilization of electric trucks and changes in required driving behavior might be inhibited by the lack of drivers that the haulage industry is currently experiencing
Inflexible delivery hours	A high degree of utilization of trucks is inhibited by the time windows during which customers can receive goods
Reduced load capacity	Due to the heavy weight of batteries, the load capacity of electric trucks is lower than for diesel counterparts, which can be an issue in segments where weight, rather than volume, is the limiting factor
Reduced flexibility	Given the limited charging infrastructure, the flexibility of electric trucks is lower than diesel trucks, which makes it difficult for haulage companies to complete deliveries outside the typical route
Lack of knowledge	A lack of knowledge regarding the technical capabilities of electric trucks has been identified, where some haulage companies might underestimate the functionality of electric trucks

6.1.2 Truck manufacturers

Below, first the enablers are presented followed by the barriers. The analysis is based on statements by truck manufacturers as well as statements from other actors concerning truck manufacturers.

Enablers for truck manufacturers

As a consequence of the current pricing of electric trucks, the truck manufacturers regarded the enabling force of subsidies as a key facilitator to reinforce the efforts put into electrified trucks. In a sense, this is quite contradictory as the truck manufacturers are the ones responsible for the pricing strategy of electric trucks. It could be argued that from a business point of view, and albeit quite cynical as well, this makes sense as subsidies that can support e.g. haulage companies in their purchasing can also support the current prices that are set by truck manufacturers. From this perspective, the truck manufacturers have a lot to gain from having said subsidies as they help in sustaining the current prices of electric trucks. However, from another perspective, subsidies could also help truck manufacturers to lower their prices. By increasing the financial power of haulage companies through subsidies, meaning that they are able to purchase more trucks, the volume of electric trucks will increase. A natural tendency in this case is that as the volume increases, the more the manufacturing firm will produce, which in turn will let the manufacturer lower the prices due to economies of scale. This is probably the raison d'être for having subsidies in the first place, to support purchasing to increase the volumes of the product which ultimately leads to lower prices. As such, subsidies act as a catalyst to the system that strengthens the reinforcing factors that contribute to e.g. the adoption rate of electric trucks.

Related to the sales processes of trucks, the truck manufacturers have to a large extent adapted their sales process to be more consultative. This goes hand-in-hand with another key enabler put forward by the truck manufacturers in that they are willing to share their knowledge to other parts of the ecosystem to speed up the transition to electric trucks. Naturally, it is beneficial for the system to have the truck manufacturers in such as consultative role. Due to the current uncertainty among the haulage companies, this role is crucial to sustain for truck manufacturers as they are the ones with the most knowledge about what truck and how that truck is utilized as efficiently as possible. It is likely that the truck manufacturers have a lot to gain from investing in close, consultative relations with their customers as well. The more they get to know their customers in-depth, the better their offerings will be, which creates a win-win situation in this case. Therefore, the consultative role of truck manufacturers is not only important for other actors in the system, it will be equally as important for themselves.

For the development, the truck manufacturers have stated that it is becoming increasingly rapid. Therefore, it is promising that electric trucks will continue to evolve both in terms of performance and affordability. This is most prominent in the battery department, where manufacturers are able to produce more capacity per volume unit. In turn, this will most likely result in lower prices for the customers. Moreover, as the capacity of batteries increases, it will open up more doors for instance to establish electric trucks in long haul transports. This is a major enabler for truck manufacturers as the development will be key to unlock more segments in the future.

The goals and requirements from the EU have proven to be an important factor in creating change in the truck industry. As the truck manufacturers have to live up to the e.g. emission requirements, it creates a force that is reshaping the industry. In one way, the requirements pave the way forward in making the industry more sustainable as it forces the development to be focused on achieving sustainable trucks, and at the same time allows the manufacturers to be flexible in what alternatives that suits the mission towards sustainability the best. Therefore, under the current circumstances, there are plenty of routes for the truck manufacturers to go in their development which allows for rigorous testing and evaluation. The enabling forces for truck manufacturers are summarized in the table below.

Table 6.3: Identified enablers for truck manufacturers

Enablers	**Explanation**
Subsidies	Subsidies that support truck purchasing will help the truck manufacturers to both decrease the prices due to larger volumes and to support wide-spread adoption of electric trucks
Adaption of sales processes	The truck manufacturers are becoming increasingly consultative in their role, which both helps in reducing uncertainty among other actors and to share information that will help to form offerings surrounding the electric truck, such as charging solutions
Rapid development	The current development of electric trucks is moving fast, which means that it will open up for more segments to be electrified, as well as lower prices due to various improvements
EU requirements	Requirements put forward by the EU have shown to create a movement in the truck industry towards more sustainable trucks and keeping options open in terms of technology which allows for testing and evaluating different alternatives

Barriers for truck manufacturers

For the truck manufacturers, the chicken and the egg problem that has been widely used throughout this thesis is a prominent barrier for truck manufacturers. The inevitable issue of whether electric trucks or charging infrastructure should be first affects the truck manufacturers due to the uncertainty that it brings.

For one, it contributes to the issue of which role the truck manufacturers should take as the problem of infrastructure is tightly connected to the roll-out of electric trucks. The truck manufacturers have a lot to gain from a roll-out of infrastructure, which raises the question of how involved they should get. Some interviewees have raised concerns regarding the translucent roles in the system, where roles are yet to be set. Truck manufacturers have already started to adapt their sales processes to be more consultative towards their customers, but this also highlights the question of whether or not truck manufacturers need to revisit their role in the ecosystem as well. Thus, there is a barrier for the truck manufacturers in knowing how much they want to widen their roles.

Due to the high prices that electric trucks currently have, there is a low demand due to the lack of affordability. Consequently, truck manufacturers might have a hard time to find the customers that are willing and able to pay the higher price initially, which might hamper the roll-out of electric trucks.

The chicken and the egg problem increases the uncertainty among the customers of truck manufacturers. This could have great effect on the sales of electric trucks, as greater uncertainty leads to decreased incentives with e.g. unclear ROIs. Therefore, the truck manufacturers have a great barrier in this regard due to the uncertain environment that the lack of infrastructure brings.

The rapid development of electric trucks has been described as an enabler above, but from a different perspective it could be a barrier as well. Due to the increased speed of development, there could be a waiting game among the customers as the more one waits the more performance per money spent one gets. This could be described as a *first mover disadvantage*, meaning that the first group of customers will pay more than the next group of customers. In other words, for the majority, the incentives to be one of the first to invest in an electric truck is therefore likely to be quite low. Therefore, a barrier could appear in this regard.

The barriers and their respective implications for truck manufacturers are presented below.

Table 6.4: Identified barriers for truck manufacturers

Barriers	**Explanation**
Ambiguous role	The role of truck manufacturers is changing with newer technologies, where a more consultative role is deemed necessary, and with a system-wide perspective it is yet unclear in what roles are necessary for the truck manufacturers to take
Low demand	Due to the high prices, there is currently a lack of demand for electric trucks as haulage companies have a hard time to afford electric trucks
Uncertainty among customers	The customers that buy trucks have a lot of uncertainty, as electric trucks give rise to new issues such as unclear ROIs and lack of flexibility, which inherently affects the truck manufacturers and their ability to sell electric trucks
The flip-side of rapid development	With rapid development comes the issue of first mover disadvantage, where some customers are likely to not invest in electric trucks as the projected development is causing a waiting game where it is better to wait for improvements and maximize the performance per money spent factor, which likely have some impact on the sales of electric trucks

6.1.3 Charging providers

Below, the enablers followed by the barriers that have been identified relating to charging providers are presented. Both statements made by charging providers, as well as statements made by other actors relating to charging providers, are included.

Enablers for charging providers

Public charging is going to be a vitally important, albeit small, part of the charging infrastructure system. The logic behind this is that, for the most part, haulage companies will be able to drive their routes powered only by at-home charging. However, in certain cases, electric trucks will have to be re-charged at some point during the day. In these cases, they will resort to using public charging infrastructure to support them throughout the rest of the day. Such routes will likely be quite rare, however they will be important to provide haulage companies with a sense of flexibility. Having strategically placed public infrastructure will enable haulage companies to buy electric trucks with smaller batteries than they would have had to buy if there was no public charging, thus reducing investment costs for haulage companies.

Because the public charging is going to be so important, and because it will allow haulage companies to invest in trucks with smaller (and cheaper) batteries, it will be of high value to haulage companies. Thus, charging providers will be able to charge a rather high price for this energy, as it will still be financially better for haulage companies to purchase this expensive charging than to buy a truck with more expensive batteries.

Another identified enabler relating to charging providers, is the fact that all roles that individual actors are going to take in the charging infrastructure system have not yet been established. This could also be considered a barrier, since this situation might create inertia where no actor wants to take the first step. Thus, it is not exactly clear who is going to be a charging provider in a future system. However, following the logic above that public charging can be quite expensive, there are financial incentives for actors to assume the role of public charging provider, as they should, at least at an early stage, be able to sell their charging at a relatively high rate. Of course, investing in public charging infrastructure only makes sense if there are electric trucks that will use them, which is a problem that will be discussed in the “Barriers”-section.

Following the facts that roles have not yet been defined regarding the charging infrastructure, and that actors are hesitant to invest in public charging infrastructure before electric trucks become more mainstream, it seems logical that public actors can be change leaders in this area. If haulage companies are hesitant to invest in electric trucks when there is no charging infrastructure in place, and charging providers are hesitant to invest in charging infrastructure before electric trucks become mainstream, public actors can unlock this inertia by either subsidizing charging solutions or operating them themselves, as doing so would accelerate the transition towards the sustainability goals that have been set.

Another enabler that was identified is that public charging stations need not be profitable by themselves. Public charging stations at so called *truck stops* creates value for other businesses near the truck stop. Following this, a property owner who owns a truck stop can likely motivate running charging stations at a loss if it leads to increased traffic to the other businesses. Moreover, when it comes to at-home charging in depots, it makes more sense for property owners to be that ones that invest in charging, rather than the haulage company that rents the property. Charging infrastructure should increase the value of the property and thus, it makes sense financially that it is the property owner that invests in it. This would decrease the burden of investment that haulage companies are expected to take, and charging would instead become an operational cost in the shape of increased rents, rather than an investment cost.

Since there is already an established infrastructure for electric cars, some discussion whether it is possible to share charging infrastructure between cars and trucks has taken place. If it was possible to build chargers that can be used both cars and trucks, that would alleviate the concerns that charging providers have regarding a low number of potential customers. However, the requirements of trucks and cars are different, so it is not clear whether or not this is possible.

Table 6.5: Identified enablers for charging providers

Enabler	**Explanation**
Public charging will be vital	Strategically placed public charging infrastructure will play a key part in enabling the transition to electric trucks, as it will increase feeling of security and flexibility for haulage companies, as well as lower their investment costs
Public charging can be expensive	Since public charging infrastructure will enable haulage companies to invest in trucks with smaller batteries, the charging can be fairly expensive, and thus there is a financial incentive for charging providers to take this place in the system
Public actors as change agents	Public actors can assume the role of starting the snowball effect, by investing in key public infrastructure if private actors are reluctant to do so due to concerns of low demand
Complementary businesses	Charging stations do not have to be profitable by themselves, if they are placed in conjunction with businesses such as restaurants, as the charging stations may lead to increased demand for the other services
Depot charging by property owners	Investing in charging infrastructure in depots will likely increase the value of the property, and therefore property owners can motivate investing in charging infrastructure as this will allow them to charge a higher rent. This would alleviate the investment burden from haulage companies, by transforming an investments cost to an operational cost
Shared infrastructure with cars	If charging stations could be shared between cars and trucks, the reluctance to invest in charging infrastructure at an early stage would likely decrease as there is already an established demand for personal car charging.

Barriers for charging providers

One of the main problem that charging providers face is that the current demand is very limited. The reason for this is that the system is currently stuck in a catch-22 situation, where haulage companies are reluctant to invest in electric trucks unless charging infrastructure is in place, and charging providers are reluctant to invest in charging infrastructure unless there are electric trucks that will use the charging stations. Following this, any investments that are made by charging providers in the present, will not start generating significant revenue until a widespread adoption of electric trucks has happened.

In order to tackle this issue, haulage companies and charging providers would have to make investments in parallel to each other so that the charging infrastructure is in place when the haulage companies start operating their electric trucks, and vice versa. However, this is challenging to achieve since, as mentioned previously, the haulage industry is characterized by high degrees of fragmentation and many small actors. Thus, it is not enough for one haulage company to make investments in parallel with charging providers, as the volume of energy required by that one haulage company is not large enough for the charging company to be able to justify an investment. Rather, a widespread collaboration is required, where many haulage companies invest, in order for it to make sense for charging providers to invest in charging infrastructure. Thus, cooperation between a large group of different actors is required for charging infrastructure to be developed.

The fact that the roles in the charging ecosystem have not yet been defined can also be considered a barrier. All actors agree that charging infrastructure is vitally important for the roll-out of electric trucks to happen, however it is unclear who is going to make these investments. It could be considered a collective action problem, where everybody in the system would benefit from the development of charging infrastructure, however no individual actor has enough incentive to invest in it and thus nobody does.

Table 6.6: Identified barriers for charging providers

Barrier	**Explanation**
Limited current demand	It is difficult for charging providers to motivate investments in charging infrastructure, as the current demand is very low due to a lack of electric trucks
Parallel investments required	In order to escape the catch-22, investments must be made in parallel by haulage companies and charging providers, so that there are electric trucks demanding charging once the charging infrastructure has been built, and vice versa
Undefined roles	It has not yet been established who should take what role in the ecosystem of charging infrastructure, which creates inertia where no individual actor has enough perceived incentive to invest in charging stations

6.1.4 Power grid companies

Below are enablers and barriers analyzed for power grid companies regarding statements both from them and other actors.

Enablers for power grid companies

One of the main enablers for power grid companies is the opportunity to widen their span in the ecosystem by undertaking more roles, such as developing charging solutions. Inherently, the power grid companies possess a lot of knowledge within the electricity domain that could be applicable in the area of electric trucks as well, such as knowledge about infrastructure and how usage affects the power outtakes in the electric grid network. This enables the power grid companies to seek new ventures in order to improve their businesses, which in turn allows them to partake in multiple roles in the electric trucks system. Therefore, the power grid companies would be able to reap the benefits not only from having the role of delivering electricity, but also from other roles.

Table 6.7: Identified enablers for power grid companies

Enablers	Explanation
New business opportunities	As the some of the roles of the electric trucks system is not yet decided on, there are opportunities for the power grid companies to widen their role to seek new ventures within the system, such as operating both as a charging provider and a conventional power grid company

Barriers for power grid companies

One of the more prominent barriers for power grid companies is that of different lead times in the system, where the power grid companies usually have much longer lead times compared to other actors in the system. As previously mentioned in the findings, the usual lead time for a large grid line is approximately 8 years. During those 8 years, the adoption of electric trucks will most likely increase quite a lot which puts further stress on the infrastructure. In a sense, the power grid companies need to be one step ahead in their prognosis to be able to cover the demand in the future.

As the amount of electric trucks increases, more stress will be put on the current grid infrastructure. Consequently, if the power demand will become too high, there is a strong likelihood that the power grid companies will need to manage the usage in order to not overload the current infrastructure. From this comes the issue of prioritization. If there are several customers who all are in high demand of more electricity, then it raises the question of who should be prioritized. The power grid companies have a responsibility to make priorities that do not affect the society at large, while precluding certain users temporarily. In turn, this has a strong likelihood to hinder flexible usage of electricity as e.g. electric trucks cannot be charged with high effects or too many at a specific hour in the future. Therefore, the role of power grid companies might change, as the electric grid infrastructure gets closer to its maximum capacity. Thus, the new role might entail a whole new mindset from this perspective.

Another barrier is that the increased use of the electric infrastructure will also increase the demand from the energy sources. If the more sustainable options of energy production, such as wind or water, will reach their respective maximum capacities, then the electricity would need to be found from elsewhere. This is where unsustainable options could come into play to support the increased demand. A situation like this could change the implications of the whole system, as electric trucks as a standalone solution relies on the fact that the electricity that it uses is produced in a sustainable way. Otherwise, the electric truck would only spatially switch the location of emissions from its exhaust to a coal plant. As such, the increase use of electric trucks have to be supported by an increase in use of renewable energy sources if the transition is to be regarded as fully sustainable, which increases the pressure on electric grid companies. It should be noted, hwoever, that in the Nordics this is unlikely to be a barrier as there is a surplus of sustainable electricity, but this barrier could appear in other countries.

Table 6.8: Identified barriers for power grid companies

Barrier	**Explanation**
Different lead times	The power grid companies have much longer lead times compared to other actors in the system, which means that they will have a hard time to keep up with the development in other sectors
Increased stress on infrastructure	As electric trucks, among other electrified appliances in the society, increase in numbers, more stress will be put on the infrastructure which in turn might cause prioritization issues when power spikes occur
Unmatched production from renewable energy sources	The need for energy sources will inherently increase as the demand for electricity increases and if the renewable energy sources cannot cover the whole demand, the system might become partly unsustainable due to its energy sources. However, this is unlikely to happen in the Nordics

6.1.5 Public actors

In the ecosystem, public actors are defined actors that work on behalf of the government and include e.g. the municipality and the traffic office. Below, the enablers and barriers for them are presented.

Enablers for public actors

First, a statement that was frequently found in the findings was that public actors can play a role in being an early adopter of electric transports. As they are such a large buyer of transports they are in a position where they can put demands on their transports regarding environmental requirements, which would incentivize haulage companies that deliver for the public actors to invest in electric trucks. Moreover, public actors also perform their own transports to some degree, and through projects such as *stadsleveransen* public actors could perform their own transports with electric trucks which would accelerate the transition to electric trucks.

Another enabler is the fact that the Västra Götaland Region has specified very ambitious goals regarding reduction of emissions coming from transport. At the current trajectory, these goals will likely not be reached, which means that public actors in the region should experience a sense of urgency and a willingness to invest time and money into reaching this goal. Consequently, investing time and money into electric trucks should be a way to move towards the goals and improving public image.

Furthermore, when it comes to public charging infrastructure, it is possible that public actors will have a role to play. As early investments into public charging infrastructure for electric trucks are unlikely to yield any profit until there has been a relatively large roll-out of electric trucks, public actors could invest themselves or subsidize investments into such infrastructure. The reason for this is related to the rationale that was explained above, that a roll-out of electric trucks would help the region reach its goals, and consequently the investment does not have to be financially profitable for the region to do it, as long as it is environmentally sound.

Moreover, public actors also play a role in designing subsidies and policies to support the transition to electric trucks. One of the most common statements made by interviewees was that this role of public actors to support the transition is vitally important. Public actors could e.g. design environmental zones where only vehicles that meet certain emission demands are allowed, or time restrict certain areas to only electric vehicles, or subsidy systems that support actors that are looking to invest into electric trucks or underlying infrastructure. Currently, a subsidy system called "klimatklivet" exists, which matches investments made by actors in e.g. electric trucks and infrastructure. Moreover, policies could also be designed to affect transport buyers rather than haulage companies, to incentivize electric transport from that direction.

Table 6.9: Identified enablers for public actors

Enabler	**Explanation**
Public actors as early adopters	Public actors can play a key role in the early phase of electric trucks, as they have a possibility to either put demands on transport they buy, or perform electric transports themselves
Ambitious goals and a sense of urgency	The ambitious goals set by the region regarding emissions means that public actors should feel a sense of urgency to act, thus likely making them more willing to invest time and money into electric trucks
The role in public charging infrastructure	Even though early investments in public charging infrastructure is unlikely to be profitable at an initial stage, public actors can motivate investments if they help reach the aforementioned emission goals
Policies and subsidies	Policies, such as environmental zones or fuel taxes, and subsidies, such as Klimatklivet, can be designed to encourage a transition to electric trucks.

Barriers for public actors

One barrier that has been identified for public actors is related to something that has been named previously, namely that the roles have not yet been fully defined in the ecosystem of electric trucks. Therefore, even though public actors might want to invest in the infrastructure, or take an active role in the ecosystem, they might not know where to best spend their money or what role to take.

Another barrier is that it is unlikely that they will make investments themselves into an industry that will likely be characterized by a free market and competition in the future. Rather, they typically perform pilot projects and subsidize actors who do want to make investments. This makes it unlikely that the public will fill the role of charging provider in the ecosystem, despite that fact that it might be a role that nobody else wants to fill in an early stage.

Another issue that has been raised is that policies set by public actors may end up having adverse effects. For instance, haulage companies have raised concerns regarding environmental zones in the city, as this runs the risk of only increasing cost of transports, which in and of itself might not be enough to encourage transition to electric trucks.

Moreover, other regulatory factors, such as the long-term stability of electricity have been raised as concerns from haulage companies. There is a worry that, as consumption and tax revenue from diesel decreases, the price of electricity will increase due to tax increases. Such concerns need to be addressed, so that a sense of security and trust among haulage companies is built. In this regard, this is very much a barrier for public actors.

Table 6.10: Identified barriers for public actors

Barrier	Explanation
Roles not yet defined	What the future ecosystem of electric trucks will look like has not yet been established, and therefore it might be difficult for public actors to know what role to assume or where to invest money
Unlikely to make investments	It is unlikely that the public will want to invest in a market that will be characterized by competition, as the public typically does not want to compete with private actors
Negative effects of policies	There is always a risk that policy decision taken by public actors, such as the implementation of environmental zones, has unintended effects and create increased cost for actors who were not intended to be targeted by the decision
Price stability of electricity	Concerns have been raised by haulage companies regarding the long-term price stability of electricity, as there is a fear that in the prices will increase in the future due to tax increases

6.1.6 Transport buyers

Below are the enablers and barriers presented for the transport buyers, based on the statements derived from the findings.

Enablers for transport buyers

One of the more prominent enablers for transport buyers, that was brought up in several interviews, was the possibility of having public actors as transport buyers to pave the way forward in making procurement requirements on sustainable transports. As the public actors generally are less price sensitive compared the private counterparts, they are in a great position to negotiate and move towards the direction of sustainability. As such, by having the public actors on board at an early stage could prove to be useful for the transition towards electric trucks. Furthermore, while the public actors put increased pressure towards sustainable transports, it could form a peer pressure towards other private actors in showcasing how and why sustainability transports matters. Ergo, the consequences of not having sustainable transports could also be highlighted to show actors what benefits there are with sustainable transports as a way to change the public opinion.

Inherently, the transport buyers possess a great deal of power in changing the current system due to the fact that they are the ones that, in the end, pay for the transports. Alas, if the transport buyers started to value and appreciate sustainable transports to a larger extent, and pay higher prices, it would create a much better position for e.g. haulage companies to be able to afford and invest in electric trucks. Moreover, the transport buyers also have a big role in establishing more security in the system as a whole by the opportunity of offering longer contracts for those actors that live up to the sustainability requirements. In turn, longer contracts would let the haulage companies have a more certain future and thus have an easier time to be able to have an ROI that is acceptable.

Table 6.11: Identified enablers for transport buyers

Enablers	**Explanation**
Public actors' procurement requirements	In order to speed up the transition and increase the demand for sustainable transports, the public actors have a crucial role in establishing procurement requirements that promote electric trucks and by that creating a ripples in the water effect
Buying power as end customers	The transport buyers are the end customers within this system, which means that they are the ones who ultimately pay the increased price that sustainability currently entails - thus they have a great deal of power in creating change by allowing longer contracts and higher prices to support and sustain electric trucks

Barriers for transport buyers

For most sectors, transports are regarded as commodities. This means that it is hard to find the incentives to motivate long relationships and higher prices, if the rest of the system do not promote such constellations. Up until now, the transport industry is very much categorized by a commodity mindset, meaning that short contracts and price pressure is the environment that haulage companies find themselves in. This could also be a result from the low entry barriers in the industry, where an entry into the transport sector as a haulage company is quite easy to do. In the end, this is also partly a result of the procurement strategy from transport buyers as it is inherently promoting the previously described environment. Naturally, considering other goods and services that an organization purchases, the transports are only a small fraction of the total expenditure each year. Therefore, prioritizing sustainable transports before other alternatives might be difficult to do and there will most probably be a lack of incentives to promote higher prices from the transport buyers' point of view. From a PR perspective, having a choice between either a sustainable product with an unsustainable transport or an unsustainable product with sustainable transport, the turn out of that choice will presumably in most cases be a sustainable product rather than sustainable transports as it much more visible to the public. This situation indicates that there is an unarticulated demand from transport buyers, which suggests that the TIS is still in its formative phase.

Table 6.12: Identified barriers for transport buyers

Barriers	Explanation
Low WTP for sustainability	As a consequence of how the system is currently outlined, the WTP among transport buyers is generally low for sustainable transports which in the end affects the whole transformative power of the system as it lessens the incentives for the rest of the system due to the commodity mindset

6.1.7 Property owners

An analysis of the enablers and barriers for property owners is made below, based on the statements found in the findings section.

Enablers for property owners

The charging infrastructure is an enabler for property owners who house different haulage companies that want to electrify their truck fleet. By offering depot charging that is readily available, property owners have an opportunity to differentiate themselves in this area. This would allow them to also take a higher rent due to the investments in charging infrastructure. From a rational point of view, the role of property owners as depot charging providers is rational as they are the ones that own the facility. As one of the experts pointed out, there is a stronger likelihood that property owners are willing to make such investments rather than haulage companies that do not own the facility. Therefore, the business case will be much more promising for property owners when it comes to depot charging. This could then have great influence on the system if the property owners realize the investments into charging solutions.

Property owners who have a public charging station could reap the benefits of increased traffic going there, such as complementary services like restaurants. In this case, the property owner would seek to invest in charging infrastructure that promotes the other services that the property owner offers. In other words, it is not the charging infrastructure per se that the property owner is predominately interested in, but rather the opportunities that comes with it. This becomes an opportunity for the property owner to market themselves and give a boost to their other businesses.

Table 6.13: Identified enablers for property owners

Enablers	Explanation
Synergies of depot charging	As the property owners in most cases are the ones that own the facilities that haulage companies use, it is possible that they can make investments in charging infrastructure as it can both increase their rent and the value of their property
Charging as a marketing tool	For property owners that have multiple businesses in the same geographical location, public charging infrastructure can be a way for them to market themselves and to increase the amount of traffic to the property which in turn can increase revenue in their other businesses

Barriers for property owners

A barrier with depot charging is that property owners might not realize the potential and value of offering charging services to their renters, i.e. haulage companies. As of now, the adoption of electric trucks is not wide-spread which in turn decreases the likelihood that the property owner will understand the value that depot charging brings as well as that the current demand is low due to the current low adoption rate of electric trucks. Therefore, it might be difficult to convince the property owners to make such investments in the early beginning of electric trucks. This might in turn hamper the transition speed to electric trucks or force haulage companies to make investments instead, for which they also can be reluctant towards as they generally rent their facility. In other words, this could perhaps result in a catch-22 where neither the haulage companies nor property owners want to make investments into depot charging.

The lack of incentives to invest in charging infrastructure could also be explained by the fact that there are most likely other low hanging fruits that they will prioritize before depot charging. Restoration work, maintenance, building new facilities, among other things, are more likely to be prioritized from the perspective of property owners. Therefore, it might be difficult for the property owner to find enough incentives to prioritize depot charging when taking the previously mentioned factors into account.

Table 6.14: Identified barriers for property owners

Barriers	Explanation
Lack of incentives to invest	Property owners will not likely be interested to make large investments in depot charging due to the current low adoption rate of electric trucks and other priorities such as maintenance

6.1.8 Freight forwarders

In the ecosystem, freight forwarders are defined as intermediaries between transport buyers and haulage companies, as haulage companies typically work as suppliers to freight forwarders and perform work for transport buyers that has been directed to them by the freight forwarders. This thesis has not found freight forwarders to be a key actor in the transition to electric trucks, as much of the discussion has not revolved around them. However, some enablers and barriers related to freight forwarders can still be identified, and they are outlined below.

Enablers for freight forwarders

First of all, some freight forwarders also operate as haulage companies, and have a fleet of trucks themselves. In such cases, that haulage company has greater financial resources than what is typically the case in the haulage industry. Moreover, since the freight forwarder has a stronger position in the ecosystem, they likely a better relationship with transport buyers, and thus are able to secure long-term contracts for their haulage company. Therefore, due to the financial resources and possibility of longer contracts, it could be argued that freight forwarder-owned haulage companies could be early adopters in the transition to electric trucks.

Another enabler for is that driving with electric trucks would likely mean positive CSR for freight forwarders. In most cases, the trucks that are operated by haulage companies driving for a freight forwarder have a large logo of the freight forwarder on the side of it, and only a small logo of the actual haulage company. Thus, if freight forwarders could encourage their suppliers to drive electric trucks, they would gain positive marketing exposure and position themselves as a progressive company that takes the challenge of global warming seriously. This also means that there could be some incentives for freight forwarders to help financing investments in electric trucks for suppliers. However, this is only true if transports by electric trucks are valued by transport buyers, which they do not appear to be at the moment.

Table 6.15: Identified enablers for freight forwarders

Enabler	Explanation
Some freight forwarders are also haulage companies	Haulage companies owned by freight forwarders likely have better financial resources and longer contracts with their transport buyers, and are thus potential early adopters of electric trucks
Electric truck as CSR and marketing	As freight forwarders' logos are clearly visible on every truck, having haulage companies operate electric trucks could position freight forwarders as a progressive company that takes responsibility for emissions, thus providing positive marketing

Barriers for freight forwarders

Other than the potential positive effects of CSR and marketing, there appear to be limited incentives for freight forwarders to facilitate a transition to electric trucks. Their role is to ensure that the needs of their transport buyers are fulfilled by a haulage company, and as long as their customers do not specifically request electric transport, there is no reason for freight forwarders to perform the transport with en electric truck. Rather, the opposite is true, as if a freight forwarder was to encourage electric transports, these transports would be more expensive than alternatives that can be provided by other freight forwarders, and their customers would switch supplier. Thus, the fact that environmentally friendly transports are ranked low by buyers compared to other factors, and that freight forwarders are service providers that have to fulfill their customers request, there is not much incentive for freight forwarders to push for electrification.

Table 6.16: Identified barriers for freight forwarders

Barrier	Explanation
Lack of incentives	Except CSR, there are no real incentives for freight forwarders to push for electric transports, unless the transport buyers request them and are willing to buy a premium for them

6.2 Relations between barriers and enablers

In this section, based on the analyses made in the previous section, the enablers and barriers are put in relations between the actors to find dynamic characteristics of the system.

6.2.1 Intrinsic incentives to invest

When looking at intrinsic incentives to invest in electric trucks or the infrastructure that supports them, there are significant differences in the system. This is highlighted by figure 6.1 below.

As identified in the figure above, there are quite some intricate relationships and incentives among the different actors. Below, a summary of the incentives of different actors is presented:

- Haulage companies - There are some incentives to invest in electric trucks as it would provide good CSR as well as a better working environment for drivers. However, there is a lack of financial incentives as transport buyers are not willing to pay more for electric transports
- Truck manufacturers - There are strong incentives to invest in developing electric trucks, as there are political requirements to reduce emissions, as well as potential for CSR and the possibility of being a leader in the electric trucks

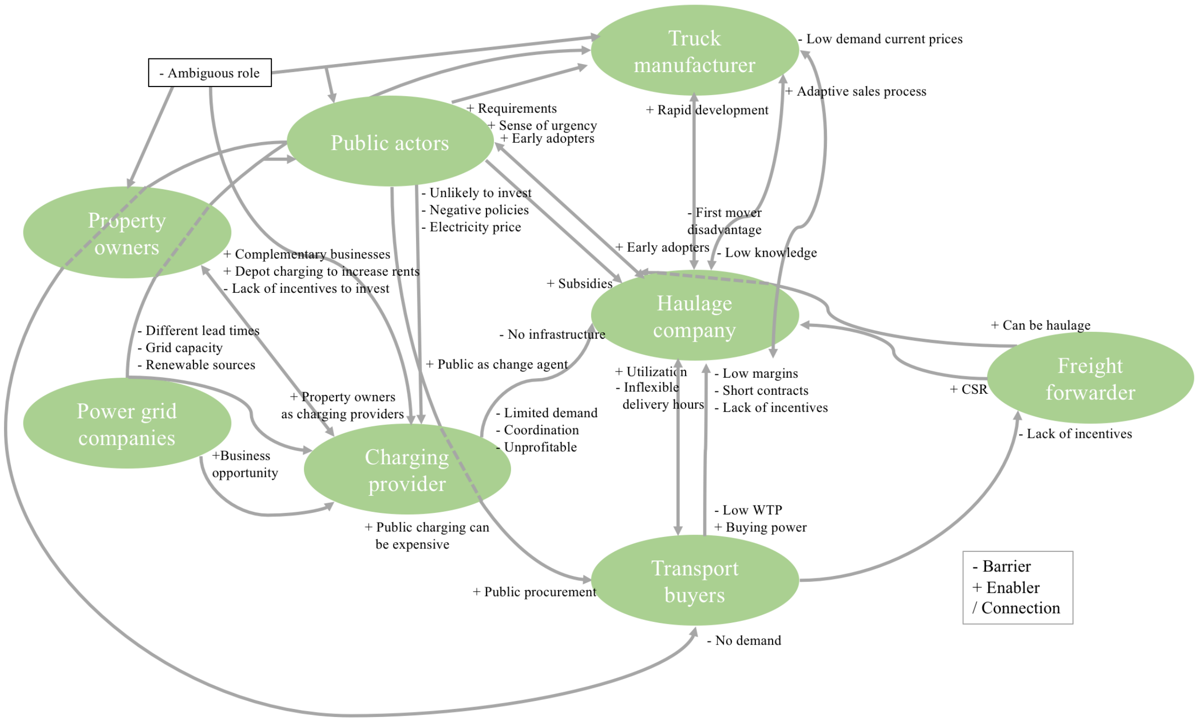

Figure 6.1: The relationships between the actors together with their enablers and barriers

segments. However, there is a limited current demand which somewhat reduces incentives.

- Charging provider - There are currently limited incentives to invest in public charging as it is unlikely to be profitable for the foreseeable future, however complementary businesses could outweigh this limited profitability. For depot-charging, there are some incentives to invest, but only if haulage companies demand it.
- Power grid companies - There are some incentives to invest, as it would lead to increased revenue. However, this is only true if there is a demand for energy.
- Public actors - There are some incentives to invest, as there is a sense of urgency for public actors to act in order to reach ambitious emission goals, which would improve public opinion and generate positive CSR.
- Transport buyers - There are limited incentives to invest, as transports are not a very "visible" part of most transport buyers' business, and they can therefore generate better CSR by focusing on "greening" other areas of their business.
- Property owners - There are some incentives to invest, as complementary businesses could benefit. However, this is only true if there is a demand for charging.
- Freight forwarders - There are some incentives to invest, as it could generate positive CSR and position them as sustainability leaders. However, there is no financial incentives as transport buyers are not willing to pay more for sustainable transports.

This list shows that some actors have high intrinsic incentives to invest, as it would provide them with positive CSR. The three actors with the highest incentives to invest seem to be public actors, truck manufacturers, and freight forwarders. The reason for public actors' high incentives to invest is that VGR have set ambitious sustainability goals and thus would generate positive public opinion by taking action to reach those goals. The reason that truck manufacturers have high incentives to invest is that (1) EU- and national requirements force them to do so, (2) they generate positive CSR by developing electric trucks, and (3) they can position themselves as a leader of manufacturing electric trucks. The reason that freight forwarders have high intrinsic incentives to invest is that transport is the core part of their business model and their logos are typically very visible on trucks, and having electric trucks would therefore give them substantially positive CSR and marketing.

The list also shows that some of the actors have very low incentives to invest. The actor that appears to have the lowest incentives to invest is transport buyers. The reason for this is that electric transports are more expensive than diesel transports. Furthermore, for most transport buyers, buying electric transport would create no significant positive marketing, as transports are not a core part of their business. As an example, if a construction company wanted to position themselves as a sustainable actor, it would likely make more sense for them to use sustainable construction material or processes, as these are visible and core parts of their business, rather than buying sustainable transports as that is a less visible part of their business. Moreover, no requirements from political actors, similar to those put on truck manufacturers, have been put on transport buyers which allows the incentives to maintain low.

For the remainder of the actors in the system, there are some incentives to invest, however these largely depend on other actors in the system. For example, haulage companies have some incentives to invest as it would provide a better working environment for drivers, as well as some positive CSR (albeit not as positive as it would be for freight forwarders). However, their incentives are heavily limited by the lack of willingness-to-pay from transport buyers. For charging providers, property owners, and power grid companies, there are some incentives to invest, however these depend on an existing demand from haulage companies, which in turn depends on the willingness-to-pay from transport buyers.

As has been shown above, the actor that has the biggest influence on the incentives of other actors to invest in electric trucks and/or the charging infrastructure, seem to be transport buyers. If transport buyers demand electric transports, a ripple effect would spread throughout the system which would increase incentives for haulage companies, and in turn the rest of the system. This is problematic, since transport buyers are the actors with the lowest intrinsic incentives to invest and thus are unlikely to do so unless pressured by outside forces. This problematic situation is further discussed below.

6.2.2 The Hallborg-Lagergren loop

As highlighted above, the market for transport can be characterized as a buyer's market, where transport buyers have a lot of bargaining power and can squeeze prices and easily switch between haulage companies. This is a consequence of the low entry barriers that characterizes the haulage industries, which creates a fragmented market with fierce competition. Since transport buyers have such a strong position in the system, they are the ones who to a large extent dictate the requirements that haulage companies have to operate under. Currently, few transport buyers value sustainable transports highly, and factors such as price and flexibility are considered more important. Since price is valued higher than sustainability, there is no financial incentive for haulage companies to operate electric vehicles rather conventional trucks. Quite the contrary, there are financial incentives for haulage companies to continue operating diesel trucks, as these trucks are currently cheaper for a significant time frame, and as such haulage companies are better able to compete on price with diesel trucks. The lack of financial incentives for haulage companies creates a low demand for electric vehicles. As was previously discussed, prices of electric trucks will start decreasing once demand and thus volume increases. This creates a grid-lock situation, where prices are too high to render any significant volume, thus preventing the prices from dropping. The situation is originated from the transport buyers, as they are the ones who dictate the market. Thus, in order for this grid-lock to be solved, somehow the willingness to pay for sustainable transports must increase from the transport buyers' side.

6.2.3 Catch-22 of charging infrastructure

Besides the fact that transport buyers have a low willingness-to-pay for electric transports, there are other factors that create uncertainty and reluctance for haulage companies to invest in electric trucks. One such factor is that there is currently no established infrastructure for public charging of electric trucks. Haulage companies value flexibility as this is often a requirement from transport buyers, and if there is no established infrastructure the flexibility of using electric trucks becomes somewhat limited. Consequently, for haulage companies to seriously consider transitioning to electric trucks, there would have to be some public charging infrastructure in place.

On the other hand, as was discussed previously, there are limited incentives for charging providers to invest in infrastructure unless there is a demand for it. If there are no, or very few, electric trucks operating in a region, it does not make any financial sense to invest in public charging infrastructure to support these trucks. This is especially palpable as it has been shown that public charging will likely be a very small part of the total charging, as the majority of charging will take place at depots. Thus, for it to make financial sense to invest in public charging infrastructure, there would have to be a relatively large amount of electric trucks that demand such charging.

This situation creates a Catch-22, where public charging infrastructure has to exist for haulage companies to invest in electric trucks, but haulage companies must invest in electric trucks for public charging infrastructure to be developed. Such a problem requires cooperation and coordination to solve, and a proposed solution for doing so is described in the final section of this analysis.

6.2.4 Ambiguous roles within the system

The system is currently characterized by a range of ambiguous roles that are yet to be taken, which increases the uncertainty in the system as it creates an environment where actors do not really know what to expect from each other. This is especially prominent in the role of charging providers. Due to the fact that the system currently lacks a set public charging infrastructure, there is not a clear vision of who should be responsible for deploying infrastructure and when. From the findings, it is evident that there are multiple actors that have shown interest in the charging infrastructure; truck manufacturers, power grid companies, public actors, and property owners; have all shown great interest in one way or another when it comes to charging. Not to mention that charging providers who currently resides in the car segment are most likely to also be interested in public charging infrastructure for electric trucks. What this results in is an increase in uncertainty as the actors cannot rely on solely one type of actor to be responsible for this question. As previously identified, the issue of infrastructure adds a lot of uncertainty to the system as it for instance contributes to the catch-22 situation that the system currently finds itself in. Hence, the uncertainty of this situation is amplified by the uncertainty from not having a clear vision of who should be responsible for charging.

Then, there is the question of what root causes there are for the ambiguous roles. For one, there are business incentives to devote efforts into establishing a charging infrastructure as there is money to be made. Truck manufacturers inherently possess a lot of data and knowledge about both their own trucks and the users, which inherently are fruitful in terms of charging infrastructure roll-out. Therefore, it makes sense that truck manufacturers are interested in this role and that they are evaluating it. Another incentive is that truck manufacturers have a great interest in solving the catch-22 in terms of electric trucks and infrastructure, where they could resolve this inert situation by simply deploying infrastructure to increase the certainty in the system with the aim of selling more electric trucks.

Another actor that have shown interest is the power grid companies. The incentives that they have are of course that being a charging provider is a natural extension of their current businesses, and currently there are some power grid companies that are present in the car charging infrastructure market. Nonetheless, one could presume that the power grid companies will most likely, in one way or the other, devote efforts into this issue and not solely as an electricity provider.

Property owners are also a group of actors that have the possibility to invest in charging infrastructure. As previously stated, there is a likelihood that property owners will show great interest in depot charging for facilities that they own. However, that is not a question of public charging. Still, public charging could also be of interest for property owners. One incentive is that public charging could be leveraged to increase the revenue from complementary businesses, e.g. by having charging infrastructure at a rest stop.

Public actors are not likely to invest in charging infrastructure for a business point of view, but rather to have an effect on the system in order to push it in the right direction. Even though that this does not create a competitive situation for the other actors in terms of charging provision, it could still create ambiguity. This ambiguity could stem from a waiting game between the actors. If other actors expect public actors to take a leading role in charging for the beginning, then it would make sense for them to wait for the roll-out to happen in order to not make costly mistakes. Therefore, public actors might cause a wait-and-see attitude among other potential charging providers.

Lastly, there are charging providers that currently are in other markets, for instance car charging. These will most likely show great interest in truck charging as well as it becomes a natural extension for their current business into a new segment. In other words, the possibility to increase their revenues is likely the most predominant driver here.

What the above-mentioned then results in is that a *cumulative uncertainty* is achieved, where the uncertainty from all the actors are inherently causing more uncertainty in the system. Looking back to the catch-22 with the lack of infrastructure, it could increase the uncertainty as well. When there is no infrastructure, and merely no electric trucks as well, then there is a great risk to take a leading role in charging infrastructure. This very risk is then causing uncertainty among those actors that are interested in investing in charging infrastructure. Phrased differently, the uncertainty from not having infrastructure is increasing the uncertainty of who should invest in infrastructure. Conversely, if there is great uncertainty in who should invest in infrastructure, it increases the uncertainty of not having infrastructure as the question of who and when it should be resolved is not in someone's ownership. This could then cause a waiting game and further strengthen the catch-22 situation.

6.3 Accelerate the transition

At the end of the day, the most important actors in the roll-out of electric trucks are haulage companies. It is the haulage companies that will pay for electric trucks and operate them. If haulage companies are not convinced of the value of operating electric trucks, it does not matter if surrounding factors, such as charging infrastructure and technological development of trucks, are in place. Only once haulage companies are willing to invest in electric trucks will the transition start to happen. Currently, there are several barriers that stand in the way of this to happen, as has been described above. Propositions for how to break down these barriers, and thus unlock the inertia in the system, are presented below.

6.3.1 Escaping the Hallborg-Lagergren loop

Regarding the Hallborg-Lagergren loop, there are several points of intervention that could be addressed. The most obvious factor that is causing this loop is that haulage companies have limited financial incentives to invest in electric trucks, as transport buyers are not willing to pay more for such transports. For the foreseeable future, electric transports will likely be more expensive than diesel transports, as the low demand for electric trucks make them more expensive to invest in. A majority of haulage companies will not be able to invest in electric trucks until prices have dropped significantly. Thus, in order for wide-spread adoption of electric trucks to happen, prices of electric trucks must decrease, which will only happen once the demand of electric trucks increase to allow for economies of scale to kick in. Following this logic, it appears that electrification of trucks will happen in stages, where the first stage is initiated by early adopters that are willing and able to pay more for the more expensive trucks. Once enough early adopters have started investing in electric trucks, prices should start to decrease and a mainstream roll-out will be more likely.

The initial roll-out is most likely to take place in urban transports, which is the lowest hanging fruit for electric trucks due to the generally low distances and well-planned routes. The most likely early adopters for haulage companies is those with the financial means to invest in electric trucks. These actors are usually those who are involved in a segment that is characterized by longer contracts and/or higher margins. In other words, haulage companies with financial stability. Therefore, it is important that the truck manufacturers, and other actors as well, identify these early adopters to attempt a roll-out within these segments. The system would greatly benefit from this, as it would both create a movement within the truck industry and also kickstart the adoption of electric trucks. Moreover, these niches will be important to showcase the use of electric trucks to inspire other segments. Based on Bergek et al. (2008), this would legitimize the system to a further extent, which is required in order for the TIS to form. This was also deemed important by some interviewees and by having concrete cases to look at, it is likely that the knowledge surrounding electric trucks among other actors will increase. In other words, the system would benefit greatly from building a foundation of knowledge as it would reduce the high levels of uncertainty, especially among haulage companies. Still, truck manufacturers play an important role in being more consultative towards their customers. It is therefore encouraged that they continue to adapt their sales processes to get closer to their customers, understand their needs, and spread knowledge on how to electrify the truck fleet. Bringing these efforts together, they should be carried out simultaneously to gain synergistic effects in order to reduce the uncertainty in the system.

However, even the potential early adopters who possess the financial means to invest in electric trucks, must have financial incentives to do so. This highlights the importance of transport buyers, as they are the ones who create financial incentives for haulage companies. As long as transport buyers are not willing to pay more for, or in some other way favor, electric transports, it is very unlikely that potential early adopters will make large scale investments in electric trucks. This is one of the most important leverage points in the system, as if this problem is solved, it is likely that ripple effects will spread throughout the system that will solve other lock-ins, such as giving clarity to the catch-22 and providing other actors with courage to deal with the question of charging infrastructure. There are a few potential ways for transport buyers to increase financial incentives for haulage companies:

1. Acknowledge that electric transports will be more expensive at an early stage, and be willing to pay more for such transports
2. Recognize that a major hurdle for a lot of haulage companies is the prevalence of short contracts, and offer long-term contracts and/or partnerships with haulage companies that invest in electric trucks
3. Make use of the strong position that big transport buyers have, and put demands regarding emissions on their transports

As was argued in the previous section, it seems that transport buyers have relatively low incentives to implement any of the above-mentioned suggestions, however, as they might not gain as much positive publicity from greening their transports as compared to greening other parts of their business. Thus, external pressure must be put on them from some direction. In fact, the way the current regulatory system is designed seems rather unintuitive, as pressures have been put on truck manufacturers to develop and sell electric trucks, while similar pressures have not been put on their customers or their customers' customers. Given this structure, it seems that a majority of the burden have been put on truck manufacturers to invest time and money into developing electric trucks until said trucks are good enough and affordable enough that the customers will demand them.

In order to speed up the transition and put less pressure on truck manufacturers, it could be argued that attention must also be given to the opposite side of the supply chain, so that demand for electric trucks is increased even at earlier stages. It would actually make more sense to start with this side of the supply chain, since transport buyers are the ones with the least intrinsic incentives to invest in electric transports, while, as has been argued previously, truck manufacturers have some intrinsic incentives to invest due to marketing and the possibility to take a leading position in the electric truck segment. Furthermore, transport buyers are the ones who dictate the market as they have such a strong position in the network, and thus if they start demanding electric transport this would create a chain reaction throughout the entire system. Given this logic, it seems obvious that some pressure must be put on transport buyers. Below, a few suggestions for doing so are presented:

1. Put restrictions on transport buyers, similar to the ones put on truck manufacturers, i.e. "by 2030, X amount of procured transports must be performed by zero-emission vehicles"
2. Create a subsidy system for transport buyers that purchase zero-emission transports, so that the financial hurdle for transport buyers is lowered

As is the case with haulage companies, early adopters among transport buyers must be identified. Even if external pressures such as the ones presented above are implemented, there might still be barriers that hinder a large scale transition to electric trucks. Early adopters could be transport buyers that have some intrinsic motivation to use public transports, such as the Västra Götaland Region, as supporting the transition to electric transports would allow them to reach their ambitious emission-goals. Furthermore, actors that can be characterized as both transports buyers and haulage companies would be fitting early adopters, as they likely have better financial capabilities to invest compared to conventional haulage companies, as well as potential for positive CSR and marketing.

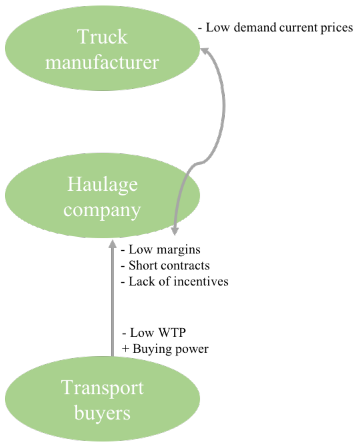

Figure 6.2: The Hallborg-Lagergren Loop

6.3.2 Process of defining the ambiguous roles & dealing with catch-22

With the scope of this thesis in mind, it is not feasible to provide with an exact list of whom should take what role. However, it is still of value to provide some perspectives on how to go about defining the roles. Moreover, the ambiguous roles are also coupled tightly to the catch-22 situation in the system as the lack of outspoken roles dilutes the uncertainty in the system, especially in regard to the catch-22 situation.

It is clear from the previous parts of the analysis that there is great uncertainty when it comes to charging infrastructure, both in terms of responsibilities and deployment, which causes further uncertainty in the system as a whole. Therefore, as a preemptive step it is deemed important to bring clarity to the issue of infrastructure, as an important step to solve the catch-22. The catch-22 is described in figure 6.3 below.

Much of the issues connected to the ambiguous roles is the lack of coordination. As previously stated, there are multiple actors that have interests in charging infrastructure from a business perspective. This is something that most likely contributes to the lack of coordination as it is very much a competitive situation between the

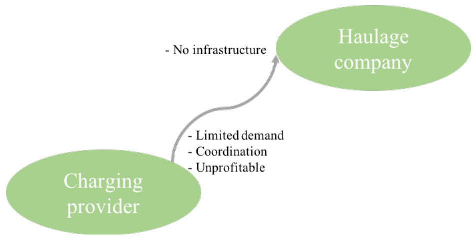

Figure 6.3: The catch-22

actors. Therefore, a coordinating force is needed to mediate between the actors in order to find a way forward in deploying infrastructure. Projects like RegionEl are therefore of great importance in this regard in order to have a neutral party who takes ownership of the questions to some extent and act as a mediator for taking the different incentives of the actors into account. Even though RegionEl has mostly taken an active role in the strategic placement of infrastructure, it is also important that they extend their role and work towards coordinating the infrastructure roll-out as this is of high need in the current system. Thus, this is especially important in the beginning of the transition, where infrastructure is one of the key drivers for speeding up the transition to electric trucks. Moreover, having initiatives that bring together different actors is also important from the perspective of Bergek et al. (2008) and the relation to knowledge. Inherently, the actors possess different types of knowledge, e.g. scientific, market, or production knowledge, which are needed to be diffused among other actors to gain a higher level of knowledge throughout the TIS. Tightly coupled to this is the *direction of search* as denoted by Bergek et al. (2008) where projects such as RegionEl influence the direction of search in the TIS.

The catch-22 of charging infrastructure requires coordination and cooperation to solve. Different actors must invest in parallel with each other. Doing this would ensure that sufficient charging infrastructure is in place once the haulage companies start operating their trucks, while simultaneously minimizing the losses for charging providers by ensuring that there is a demand for the infrastructure they develop. In order to achieve such coordination, platforms that facilitate cooperation as well as multi-actor projects facilitated by a neutral party are of utmost importance. Currently, in the region of Västra Götaland, there are such ongoing projects. One such project is RegionEl, which has been a key source of data for this study. A key take-away from RegionEl is the importance of gathering data from haulage companies regarding driving routes. By gaining access to such data from a range of different haulage companies, similarities between them can be found, such as locations where drivers frequently stop for lunch. In such locations, charging stations could be deployed with a certainty that the demand will be high.

As described above, RegionEl provides charging providers with a sense of security regarding the geographical placements of their charging stations. However, even though uncertainty regarding the geographical placement of charging stations is lowered, the issue of financial incentives still remain. If charging providers are not convinced that there will be enough electric trucks that use their chargers, it does not matter much if they are strategically placed, as the demand is still too low to turn a profit. Therefore, the business case needs to be addressed for both haulage companies and charging providers, as most of the actors do not currently see a viable business opportunity. This is something that is of importance to solve, as a viable business case for more actors will both increase the incentives and the likelihood to speed up the transition. Once again, RegionEl or similar initiatives could play an important role here as a neutral actor that do not really have any incentives to only gain themselves in a system's transition, as their purpose is to pave the way forward into this transition. The ecosystem of electric trucks is characterized by multiple actors with different stakes and motives, and in such a system it is likely important to have an actor with a neutral role that can provide objective and system-wide perspective to guide the transition. Such an impartial actor could take a key role in communicating with public actors, to ensure that they are given an objective and overarching view of the system, that is not colored by financial incentives. This is important, as the transition to electric trucks would benefit greatly from public means, and it is therefore important that these efforts are deployed where they make the most difference.

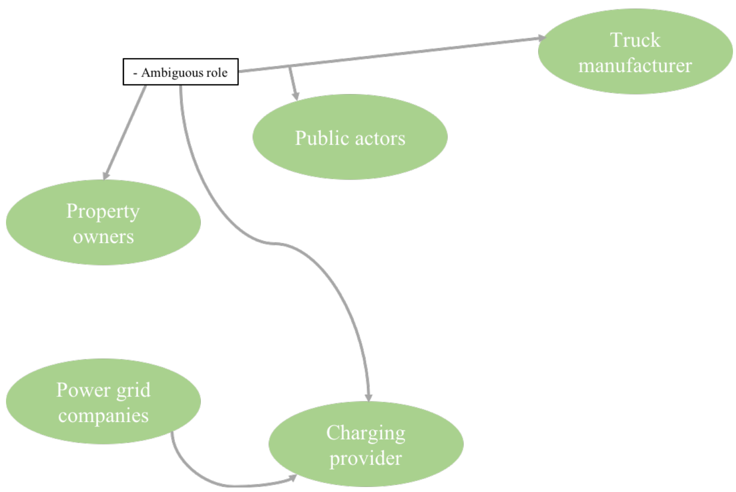

Figure 6.4: The ambiguous roles

Similar to the case of transport buyers and haulage companies, it is vital to identify actors that could be early adopters of charging providing. Since it is unlikely that providing charging will be profitable at an early stage, early adopters must be actors that gain other advantages from providing charging. Such advantages could be an improved public image, or the pursuit of a higher goal. Furthermore, early adopters must possess the financial means to be able to run charging stations at a loss. Alternatively, subsidies from the public could aid in incentivizing charging providers to develop infrastructure at an early stage. However, it should be noted that, at an early stage charging infrastructure might not be the limiting factor. This is due to the fact that the firs trucks to be electrified will most likely be operating in an urban setting, where the technology is good enough to perform most of the transports. Therefore, if haulage companies can get over the psychological barrier of reduced flexibility, and start to make an initial transition to electric trucks by replacing a small part of their fleet, a customer base would start to emerge for charging providers, thus making the financial incentives for them higher. From this perspective, it could be argued that the Catch-22 might resolve itself if haulage companies trust the technology and are willing to sacrifice some flexibility. Such an organic transition would be slow, however, as only small parts of haulage companies' fleets would be replaced until infrastructure is developed, and developing infrastructure is a lengthy process due to the lead times from grid providers. Therefore, in order to achieve as rapid a transition as possible, coordination between haulage companies and charging providers is desirable.

6.3.3 Early steps to accelerate the transition

In the previous sections, it was shown that there are several key strategies that can be implemented to promote and speed up a transition to electric trucks. However, these strategies are on a rather high level of abstraction, and some more concrete steps might need to be outlined to create movement at this early stage. Therefore, a plan for early initiatives that should be implemented are described in the following section. First of all, it is important to identify early adopters in three areas: transport buyers, haulage companies, and charging providers.

Firstly, the system would benefit greatly by looking at transport buyers and their role in the transition. By doing this, the demand for electric transports would increase, which would enable haulage companies to have financial incentives to invest in electric trucks. This would send ripple effects through the entire system and start a positive loop where the demand for electric trucks increases and the price for electric trucks decreases. Such a reduction in price would allow additional haulage companies to add electric trucks to their fleet and accelerate the transition.

Secondly, haulage companies that can be early adopters are crucial to identify since only a small amount of haulage companies have the financial means to invest in electric trucks at the current price levels. If such early adopters show the rest of the system that it is feasible to operate with a fleet consisting of electric trucks to some degree, it will likely inspire others to invest as well. This is important, as showcasing success stories has been identified as a major enabler for the transition to electric trucks. Furthermore, it will also increase the volume of electric trucks that are produced, which will allow for economies of scale for truck manufacturers, thus lowering the prices. This would then create a positive loop where prices decrease as the produced volume increases.

Thirdly, it is vital to identify actors that can be charging providers in an early stage. For the early adopters, operating charging infrastructure will likely not be profitable by itself initially, as the volume of electric trucks will be low at the start. Because of this, potential early adopters are likely reluctant to invest, and therefore it is important to find actors that have the financial means and complementary products and services that can benefit from operating charging infrastructure. It is evident from the findings that establishing a charging infrastructure would increase the likelihood that haulage companies invest in electric trucks. Haulage companies appreciate the increased flexibility that public charging provides, as well as feelings of security. This would also mitigate the risks for over-capacity in terms of the battery size of the electric trucks, which inherently is expensive, and thus ensuring that investment costs are lower for haulage companies. Consequently, establishing a public charging infrastructure would increase the incentives to invest from haulage companies, as it would promote flexibility and feelings of security among haulage companies, while simultaneously reducing investment costs for them.

Second of all, even though the three above-mentioned actors are a good start, it is also needed to look into certain applications of electric trucks in order to find the niches that electric trucks are currently well suited for. Urban transports seem to be the lowest hanging fruit in the system for an initial roll-out of electric trucks. More importantly, it is advised to start with niche players that have the financial strength to be early adopters. These are generally haulage companies that have longer contracts and/or higher margins. Furthermore, for urban transports, public charging is not essential to start a small-scale transition which in turn would alleviate the issue of the current catch-22 situation. Still, there is a need for depot charging, which in turn demands a collaboration between haulage companies and other actors that are involved in setting up a charging infrastructure at the terminal. Most presumably, this will not be a difficult question to tackle as long as the business case is beneficial for the actors involved.

Third of all, it also necessary to have a neutral actor that represents the overview of the system in order to ensure that public means are directed into the most important leverage points in the system. Moreover, this neutral role is also deemed as important for coordinating the deployment of infrastructure and create a cooperative environment. Such complex transitions as electrification of trucks surely deems coordination and cooperation in order to make a transition that is fruitful for everyone involved in the system.

6.4 Electrification of trucks as a system innovation

The transition to electric trucks exhibits all the qualities that is required to be considered a system innovation. First of all, it is relating to the basic human need of mobility. Second, the transition affects a majority of the actors in the system, as haulage companies, drivers, truck manufacturers, freight forwarders, etc. are affected by the change. Third, it is indeed encompassing both technological and societal/cultural change (due to changed behavior in terms of e.g. planning routes), which further indicates the fact that this is a system innovation. Moreover, the transition is multi-actor, multi-factor, and multi-level:

- Multi-actor: In order for a transition of trucks to happen, several actors need to act together, such as haulage companies, transport buyers, and truck man-

ufacturer
- Multi-factor: Several different factors need to be addressed to create a change within the system, as several lock-ins exist in it
- Multi-level: Transition to electric trucks requires change on different levels. On the micro-level, individual actors need to dare to invest in electric trucks and be early adopters, and on the meso-level, rules and regulation must be adapted to incentivize electric trucks. However, changes on the macro-level have not been identified in this thesis.

Even though it is a system innovation, and thus complex in nature, it should be noted that the system consists of a limited amount of distinguishable actors that are already cooperating. Thus the fact that it is a system innovation is not a great challenge in itself as the system is of a manageable complexity where the traditional relationships and roles are not rendered obsolete by a technological change. However, some relationships and roles are more ambiguous compared to the established system as described in the previous sections.

The findings have shown that electric trucks have found uses is some niche areas, as pilot projects are up and running. Furthermore, there is an established ecosystem of engineers and producers surrounding electric trucks. A dominant design regarding the technology has to a large extent been established, as standardization of charging outlets have been developed and battery-driven trucks have to a large degree been accepted as the future technology. This indicates that the technology is in the second phase that Geels (2005) identifies, which means that it is in a relatively early stage still. Furthermore, in accordance with Bergek et al. (2008) the market seems to be between a nursing and bridging phase as the size of the market is still quite limited but is beginning to grow in terms of volume. Thus, both in technological and market terms, the system seems to be in its early stages. This is also strengthened by the indicators put forward by Bergek et al. (2008) which indicates that the TIS is in a formative phase. Relating to the uncertainty in the system, this could very well be an explaining factor to why there exists high levels of uncertainty. Moreover, the pathway that the system innovation of electric trucks has taken can be characterized as what Geels (2005) describes as “wide transformation”, as the experimentation efforts in the system are mainly performed by established actors.

7 Discussion

This thesis aimed to answer the two research questions that were posed in the beginning of this thesis, i.e. to explore the system of electric trucks in the Västra Götaland region. The two research questions were:

- What are the barriers and enablers of the adoption and transition to electrified trucks, in general, and in Västra Götaland in particular?
- What key interventions could be made to speed up the transition in relation to the previously defined barriers and enablers?

7.1 Contributions

The results indicate that there are some major barriers as well as enablers in the transition to electric trucks. The aim of this thesis was to highlight the intricacies within the system to all stakeholders involved, where our goal was to lay a foundation of knowledge on how to create change. A plethora of enablers and barriers have been identified, and a summary of the most important ones are outlined below:

- Enabler - Subsidies to incentivize investments in electric trucks
- Enabler - Rapid development of technology
- Enabler - Lower marginal cost of driving
- Enabler - Technically feasible to electrify many routes already

- Barrier - Low margins and short contracts for haulage companies
- Barrier - High investment cost of electric trucks
- Barrier - Low willingness-to-pay from transport buyers
- Barrier - Lack of established charging infrastructure

We believe that our thesis will play a role in the transition as we have, throughout the interviews, found evidence that both viewpoints and incentives differ among the various actors in the system. Therefore, we believe that there is value to be had from this thesis in that regard as we are showcasing the relations between the actors, which inherently need to be considered in order to create system-wide change. In this regard, we argue that we have contributed with useful insights both in a local as well as general context. It should be noted, however, that there is still work to do within this field, but that will be further explored in the implications section below.

7.1.1 The relation to previous literature

To a large extent, the findings of this thesis support what has been identified in previous literature. Key barriers such as higher procurement cost, lower loading capacity, and a lack of charging infrastructure have been identified previously and this thesis therefore supports the claim that these are significant barriers for the electrification of trucks. One barrier that has not been prominently featured in previous literature is the importance of length of contracts between transport buyers and haulage companies. Thus, one contribution from this thesis is the suggestion that haulage companies with long contract lengths are potential candidates for early adoption of electric trucks. Furthermore, while previous literature has identified that low willingness-to-pay from transport buyers is a barrier, this thesis highlights just how significant that barrier is and the inertia that it creates. Previous literature has merely identified it as one barrier among many, however the contribution of this thesis indicates that it is a key leverage point that, if addressed, could unlock inertia within the entire system.

7.2 Methodology

This thesis have followed the research process explained in the methods chapter, where the limitations and implications of the research process is discussed below.

To start with, we used predominately semi-structured interviews as the method to gather data on what the system looks like currently. We believe that this method was proper in the sense that interacting with the actors involved in the system is a key entry-point in unlocking the data that resides within the system. In this regard, we gained valuable data as all actors had a role in the system which gave us good perspectives on the current status. However, as the system is quite complex and vast, we did unfortunately not have the opportunity to engage with every type of actor. Therefore, this might have an impact on the results of the study as we sometimes had to rely on information about one actor from a secondary data point from e.g. an interview with an expert. Consequently, if we were to perform the study once again or have had a longer time span to work with, it is to our best of knowledge useful to engage with all actors to confirm what other interviewees had stated. Unfortunately, this was not feasible in this thesis due to resource constraints.

We also attended a webinar held by RegionEl where various actors gave presentations on their perspectives for electrified trucks. This was very useful as it gave us further insights from actors that we did not have the opportunity to interview. The presentations held did to a large extent confirm the secondary data about certain actors that we had derived from interviews. However, we would still have liked to engaged deeper with all actors. In the end, we still believe that our data gathering process was performed well and that it resulted in data that was rich enough to perform analysis and make conclusions on.

The analysis was split up in a three-step process as described in the methods chapter with inspiration from the process put forward by Bergek et al. (2008) as well as Geels (2005). Overall, we think that the analysis process gave us depth in finding ways to look at our data and to provide with new, unraveling perspectives on the system. Due to the close relation between data and analysis, we believe that the analysis could have been improved with the use of more data. As previously stated, we did not have the opportunity to directly engage with all actors in the system. It is not easy to explicitly state the direct impacts of not having interviews with all actors, but it is imperative that it should have some impacts on the end result. This poses the question if the analysis process could have been altered in an attempt to compensate for the shortfall of perspectives. In a sense, if we had more time to work through the analysis multiple times, this could have alleviated some of the concerns regarding the rigorousness of it as it could have highlighted some findings or analysis points that had benefited from more iteration. However, in the end, we are certain that our process had led to interesting viewpoints of the system, but we still acknowledge that it could have been developed further by e.g. performing more interviews.

The backcasting process was both rewarding and fun, but frustrating at times as it deals with quite complex issues and system-wide problems. Due to the intricate layout of the backcasting process, we believe that backcasting is good to take a system's perspective in order to find leverage points where one could intervene and create change. Moreover, we think that even though the backcasting process might come across as quite abstract and complex, it is needed as it is used to study very complex phenomena in the society. Thus, backcasting gave us the proper tools to delve into the mechanisms and the relations of a system, which inherently is much needed when working with system's change.

7.3 Implications

This section is divided into two parts - one which is focusing on the implications that this study has for research, and the other focusing on the implications for practice.

7.3.1 Implications for researchers

This study has taken a very broad view of electrification of trucks, which unfortunately means that some nuance is lost along the way. Groups such as the haulage industry or transport buyers have to a large extent been viewed as homogeneous groups, however the reality is more complex. Further research looking into how barriers and enablers differ between different segments of the transport industry would therefore be beneficial, as this would help highlight potential early adopters of electric trucks.

Moreover, as this study has taken a system perspective, a broad but potentially narrow understanding of the individual actors' viewpoints has been gained. Thus, it could be of value for further researchers to delve deeper into different actors in the system to fully understand their viewpoints. The actors that have been identified as most relevant for the transition to electrification in this thesis, and that might therefore be of most interest to research further, are haulage companies and transport buyers.

Furthermore, another area of research that could be of interest to look at, is a more technological perspective of the system. Inherently, there are several options to create an emissions-free truck industry other than through electrification. Therefore, it is advised that further research could take a more technical perspective in comparing the different technologies that currently is offered, and by that creating new knowledge on what type of technology that is deemed to be fruitful for making the system more sustainable.

7.3.2 Implications for theory

This thesis is based on the methodology developed by Bergek et al. (2008). However, the methodology has not been followed precisely, rather it has acted as a source of inspiration for how to design the research process and to guide the thinking behind the analysis. Furthermore, the methodology inspired us regarding what the most important factors were to look at, such as actors, dynamic relations (described by Bergek et al. (2008) as functions), and barriers and enablers. The application of the methodology in this thesis highlights that there is a need to adapt the process developed by Bergek et al. (2008) depending on the situation. Further research within this domain might be valuable, as adaptability of analysis methods should be regarded as a point of interest due to the fact that different systems might entail different analysis methods. This has at least proven to be the case for us in this thesis. In other words, this suggests that the framework by Bergek et al. (2008) might need to be adapted to fit with the situation in practice.

Furthermore, within the realm of system innovations as described by Elzen and Wieczoreck (2005), there are several characteristics that the studied system needs to fulfill in order to be regarded as a system innovation. In this thesis, we have found that the system for electric trucks in the Västra Götaland region is very much a system innovation. Therefore, we can confirm the requirements put forward by Elzen and Wieczoreck (2005). Geels (2005) posits that a system goes through four phases which are described in the previous literature chapter. We regarded the system of electric trucks to be in phase two. However, we have not identified changes in the macro level of the system due to the fact that we have looked into the micro and meso level of the studied system. Therefore, it is advised that further research looks into the macro level of the same system and how that relates to previous theory.

7.3.3 Implications for practice

Admittedly, we have had a very industry-close perspective on things throughout this thesis. In practice, the main implications are the barriers and enablers for individual actors, how the actors relate to each other with respect to their respective barriers and enablers, and lastly how to go about creating change in an inert system with the introduction of “new” technology. In the end, we found that there are three major lock-ins within the system that need to be resolved. These are the three major implications for practitioners, together with some ideas on how to overcome these three hurdles. In summary, the three main points of intervention are:

- The low willingness-to-pay from transport buyers, which creates a negative feedback loop where demand as well as price for electric trucks is negatively affected
- The requirement of coordination between haulage companies and charging providers, to ensure that charging infrastructure and electric trucks are rolled out in parallel with each other
- The ambiguous roles for charging infrastructure, as it is unclear who should take what role within the system where there are several possible actors that have shown interest in the question

Another implication is that this study highlights the sheer complexity in system's change and that there are a handful of factors that need to be taken into consideration. We are almost certain that some perspectives have fallen short in this thesis, which calls for further research in this regard by looking deeper into each of the actors as there are actors with different characteristics even though they look much alike on the surface. We have to some extent mentioned this throughout the report in that e.g. haulage companies have different incentives on why to electrify their fleet. Thus, we advise that further research should be invested in this area to delve deeper into the intricacies within one category of actors.

8 | Conclusion

This study has brought to light several barriers and enablers relating to the transition to electric trucks in the region of Västra Götaland from the perspectives of various actors. Some of the most pressing barriers that need to be addressed to accelerate the transition to electric trucks are the low willingness-to-pay from transport buyers, the catch-22 of charging infrastructure, and the ambiguous roles within the ecosystem of charging infrastructure.

The low willingness-to-pay from transport buyers creates a negative feedback loop, where haulage companies do not see any financial incentives to invest in electric trucks. Electric trucks are currently more expensive than conventional diesel trucks, and if their customers are not willing to pay more for electric transports, haulage companies see no reason to invest in electric trucks. This creates a situation where the demand for electric trucks remains relatively low, which prevents economies of scale from kicking in, thus keeping prices high. Since most haulage companies have low margins, they are unable to invest in the more expensive electric trucks. However, if transport buyers started demanding sustainable transports, and were willing to pay more for them, some haulage companies would see an incentive to invest in electric trucks. This would increase the demand for electric trucks, thus allowing prices to decline and enable more haulage companies to afford electric trucks, as well as see the financial incentive to invest in them. Initially, demand from transport buyers can be increased by public initiatives, such as introducing a subsidy-system for procuring zero-emission transports.

The catch-22 of charging infrastructure can be summarized as follows: "If charging providers are to invest in public charging infrastructure, there must be electric trucks that can use it to make it financially viable, however for haulage companies to invest in electric trucks, there must be public charging infrastructure in place." This situation creates a lock-in where neither charging providers nor haulage companies are willing to take the first step. Charging providers are unwilling to invest in public charging infrastructure as they know that it will be an unprofitable investment for the foreseeable future, due to a lacking demand. On the other hand, haulage companies are unwilling to invest in electric trucks, as they fear that, without sufficient charging infrastructure, their flexibility will be significantly reduced, which can be devastating for haulage companies. Thus, in order to solve this situation, coordination and cooperation between haulage companies and charging providers is required to ensure that parallel investments are made, so that charging infrastructure is in place when the electric trucks have been purchased, and vice versa. Such coordination can be facilitated by a neutral party, and in the region of Västra Götaland *RegionEl* fulfills this role to a certain degree.

Finally, the issue of ambiguous roles is a pressing issue that is related to the aforementioned catch-22. It is not yet clear who will invest in public charging infrastructure, and the catch-22 makes potential charging providers even less certain whether to invest. Therefore, it is vital to identify potential early adopters that can assume the role of charging provider. Since it is unlikely that providing charging will be profitable at an early stage, such early adopters will likely be actors that gain other advantages from investing in charging. Such actors can be e.g. property owners that own *truck stops*, where peripheral businesses such as lunch restaurants would benefit from having trucks stop there. Furthermore, such early adopters must possess the financial means to lead the investments in public charging, as it is likely that it will be unprofitable initially. However, it should be mentioned that public charging infrastructure might not be the limiting factor, as a large portion of urban transports will very likely be possible to perform without any public charging. Therefore, an initial small-scale transition to electric trucks would be possible without public charging infrastructure, which would create an established customer base for potential charging providers to serve, and thus the aforementioned catch-22 might resolve itself. However, the flexibility and sense of security that public charging provides for truck manufacturers might be so significant that it is not realistic to expect a small-scale transition without infrastructure.

The transition to electric trucks can be described as a systems innovation, as it involves multiple actors and multiple factors on multiple levels, and as such it requires communication and coordination to achieve. Electric trucks are still in a relatively early stage of their lifespan, as only small-scale pilot projects have been started, however a dominant design has emerged and an established base of engineers from multiple actors are working to further the technology. Rest assured, an increased diffusion of electric trucks will happen in the future, and if the aforementioned challenges are addressed, the transition will be quicker. Thus, if the goal of reduced emissions in the region is to be realized, it is advised that the recommendations made in this thesis are taken into consideration.

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A | Appendix A

A.1 Topic guide

Actors

- What actors are involved in the transition to electric trucks?
- What actors are deemed important for the transition to happen?
- What actors need to change and in what way?
- Do you think that your role in the system needs to change to transition to electric trucks?
- Are there any new relations that will form in the transition?
- Will you need to organize differently to adapt to electric trucks?

Economy

- What financial barriers do you see in a transition?
- What financial enablers do you see in a transition?
- Where in the system would funds make the biggest difference?
- Do you think that a transition would increase the financial risk for your organization?
- Are there any new cost or income streams that are formed by a transition to electric trucks?

Infrastructure

- Provided that electric trucks existed, what infrastructure is needed?
- How should such infrastructure be deployed?
- Who should deploy infrastructure?
- Are there any actors that are more likely to be interested in infrastructure?
- What does the future of goods transports by road in the region look like?

Barriers and enablers

- What barriers do you see in the transition?
- What enablers do you see in the transition?
- Are there any specific pressing issues in the current system?
- What issues can you see for the rest of the system?
- What enabling forces can you see for the rest of the system?
- What do you think is the biggest hurdle to overcome?

A.2 The categorization of statements

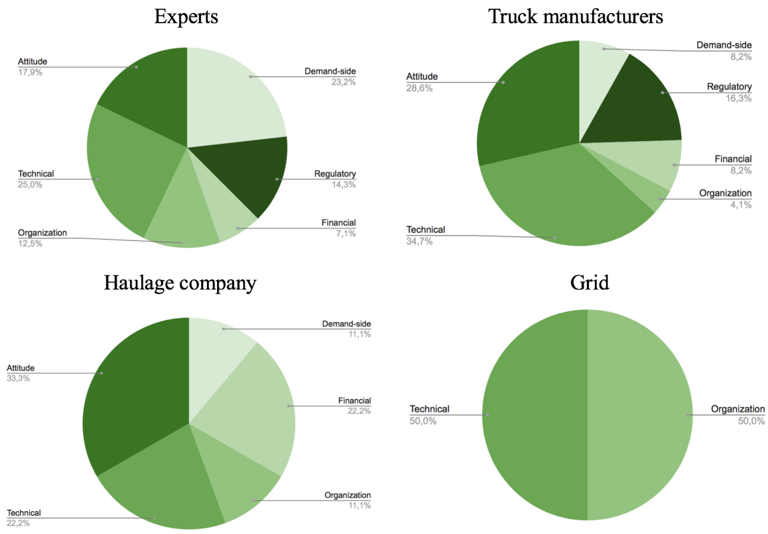

Figure A.1: Enablers

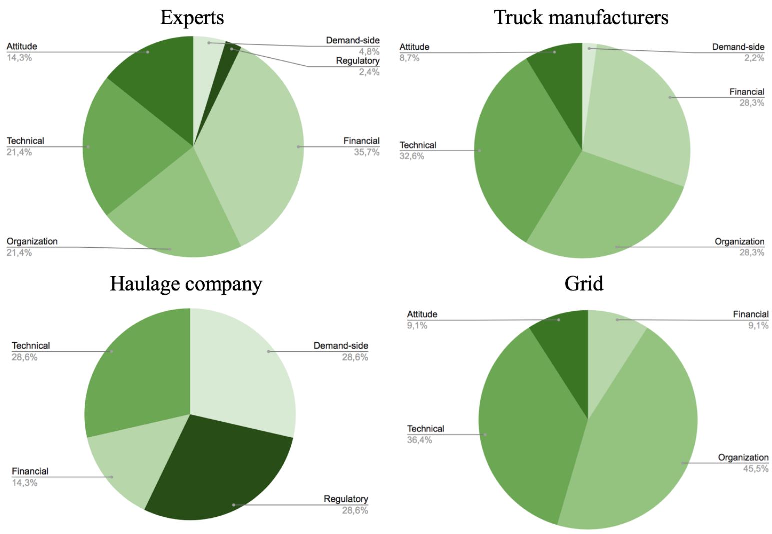

Figure A.2: Barriers