STOP TO RECHARGE WILL BE A THING OF THE PAST

AN EXPLORATIVE AND PROBLEM-SOLVING STUDY ON IMPLEMENTING AN ELECTRIC ROAD SYSTEM IN PORTS

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Master's thesis, MIOM05
Division of Production Management
May 2023

Preface

This thesis represents the final and concluding part of our five-year long education at Lund University to obtain our Master of Science in Industrial Engineering and Management. The thesis was conducted in collaboration with the company Elonroad located in Lund.

During the writing of the thesis, several persons have supported and guided us to whom we would like to express our gratitude. Firstly, we extend our sincere appreciation to Ulf Silbersky, our mentor at the Division of Production Management, for helping us throughout the process with valuable feedback, insights, and constant encouragement. Secondly, we would like to thank Elonroad for warmly welcoming us and assisting us on this journey. Additionally, we would like to express a special thanks to Anton Tortstensson, our mentor at Elonroad, for his unwavering support and insightful contributions.

Finally, we would like to thank all the people who took the time to participate in our interviews. Your contributions have been incredibly helpful to our work and the thesis would not have been possible without your help.

Lund, May 2023

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Abstract

Electric road systems can be defined as a system transferring energy from a road to an electric vehicle while the vehicle is in motion, either to power the vehicle's movement or to charge its batteries. This thesis aimed to investigate how this relatively new technology of electric road systems could be implemented in a port. The research was conducted by having a two-fold research purpose. Firstly, the research identified which factors were relevant to consider when implementing an electric road system in a port. Secondly, the study examined how ports differed in terms of how suited they were for implementing an electric road system based on the previously identified factors. The work was limited to only studying the electric road system technology developed by Elonroad, and to mainly focus on one type of port operation, namely container terminals. A literature study of current knowledge of the electric road system technology and container terminals was conducted, followed by several interviews with experts to establish an in-depth understanding of these two previously unrelated topics. Based on the information collected, this study created a framework containing the most relevant aspects to consider when implementing an electric road system in a container terminal. The framework and its included parameters then formed the foundation for creating a tool used for identifying differences in the compatibility of an electric road system implementation between various container terminals. A pilot test was conducted on this tool in order to evaluate and demonstrate the usefulness and applicability of the tool. The results of the study showed that there are four overarching factors with thirteen underlying parameters that are relevant to consider when investigating an electric road system implementation in a port. Moreover, it was shown that different ports were variously suitable for an electric road system implementation when examining them using the thirteen identified parameters.

Keywords: Case study, Electric Road System, Ports, Container terminals, Electrification, Implementation compatibility, Closed-looped transportation systems

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Abbreviations

ADT - Average Daily Traffic
AGV - Automated Guided Vehicle
CARB - California Air Resource Board
ERS - Electric Road System
ESPO - European Sea Ports Organisation
EU - European Union
EV - Electric Vehicle
FCV - Fully Compatible Vehicles
HVO - Hydrotreated Vegetable Oil
ITS - International Transportation Service
NCV - Not Compatible Vehicles
NOx - Nitrogen Oxide
PCV - Partially Compatible Vehicles
RMG - Rail Mounted Gantry
RTG - Rubber Tired Gantry
SDG - Sustainable Development Goals
STS - Ship-To-Shore
TEN-T - Trans-European Transport Network
TEU - Twenty-Foot Equivalent
UN - United Nations

1 Introduction

The introducing chapter provides the background context, purpose, and scope of the thesis. The two main research questions, RQ1 and RQ2, are also introduced along with a problem discussion and the delimitations of the study.

1.1 Background

On the 12th of December 2015 at the United Nations (UN) Climate Change Conference in Paris, leaders from all around the world reached a historical breakthrough when forming the Paris Agreement. This international treaty on climate change is today adopted by 194 parties worldwide and has a goal of limiting the global temperature by reducing global greenhouse gas emissions (United Nations, n.d.:a). In accordance with the Paris Agreement, today's emission levels are aimed at being drastically reduced and reach net zero by 2050 (United Nations, n.d.:b). In 2020, the burning of fossil fuels to power the road transport sector accounted for 11.9 percent of the total global greenhouse gas emissions. An electrification of this sector could therefore lead to substantial reductions in global emissions and take the Paris Agreement one step closer to reaching its emission net zero goal by 2050 (Ritchie, 2020). Electric Vehicles (EVs) are likely to play an important role in this future electrification of the road transport sector. The adaptation of EVs is well underway but its uptake has been limited due to limited battery ranges, high purchase costs and a lack of charging convenience. A relatively new approach to overcome these challenges is Electric Road Systems (ERS), a charging infrastructure connected to the road allowing vehicles to charge their batteries while driving (Bateman *et al.*, 2018, 3-4). This technology allows for reduced sizes of batteries in EVs, improved charging convenience and in theory, enable EVs to drive with infinite range (Elonroad, n.d.:a).

1.1.1 Electric Road Systems

ERS can be defined as a system transferring energy from a road to an EV while the vehicle is in motion, either to power the vehicle's movement or to charge its batteries. (RISE, 2021, 3) All current types of ERS consist of five underlying subsystems. The first subsystem is electricity supply, covering how electricity is transported and distributed through a grid from the initial generation source to the electric road. The second subsystem is power transfer, handling the detection of vehicles and the transferring of power from the rail to the vehicle. The vehicle itself is also a subsystem which includes all necessary components required in the vehicle to be able to use the ERS for charging. Road operations is the fourth subsystem handling the payment and billing of the energy use and the access to the electricity from the road based on vehicle identification. The last subsystem is the road, which refers to the design of the road and its markings, signs and surrounding safety barriers (Gustavsson, et al., 2019, 7-8).

There are three main power transfer technologies used in current ERS solutions. These are either using conductive or inductive technologies to transfer the energy from the power grid to the EV. Conductive power transfer technologies use a direct contact between the power unit and the vehicle, either by using overhead conductive lines or rails attached to a road surface. The inductive power transfer technology, on the other hand, transfers the energy wirelessly using primary coils attached to the road surface to create magnetic fields to power the EV. (Gustavsson, *et al.*, 2019, 8) There are currently a few different players developing and testing different types of ERS solutions, using both conductive and inductive technologies. Siemens, Alstom, Elonroad, Elways and Electreon are some examples of companies that today are operating in the ERS industry. (Siemens, n.d.; Alstom, 2017; Elonroad, n.d.:b; Elways, n.d.; Electreon, n.d.).

1.1.2 Elonroad

With a vision to reduce range anxiety for electric car owners, Dan Zethraeus founded the Swedish ERS supplier Elonroad. By using conductive rails, Elonroad is aiming to revolutionise the transportation industry forever. The company's electric road solution supplies EVs with power by using a pick-up attached beneath the vehicle. This pick-up is in direct contact with a rail, supplying power with 97 percent efficiency to both drive the vehicle's motion and to charge the vehicle's batteries. The supplement of power can be done both statically when the vehicle is parked, and dynamically while the vehicle is in motion. The conductive rail is also equipped with multiple sensors collecting and analysing data, ensuring the road is operational at all times (Elonroad, n.d.:a).

Today, Elonroad is well underway in testing their ERS solution in real-world settings. They are currently part of a pilot project called *EVolution Road* in Lund, Sweden. This project is a collaboration between different public and private stakeholders with the purpose of gaining more knowledge on the potential of the ERS technology as a complement in a future fossil-free transport system (Evolution Road, n.d.). There is a need for similar tests and projects to be done in order to explore more possible business cases, scale up the customer base and define the next steps in the commercialisation process for Elonroad's ERS. Ports are currently one business case considered to be of great interest, as it is thought to be a gateway into large-scale deployment and a step in the right direction to reach their vision. A vision to be an enabler for sustainable transportation and make fossil fuel a thing of the past (Elonroad, n.d.:c).

1.1.3 Ports

International trade has grown to become an important pillar in the world economy since it enables easier connection between different countries and markets, and facilitates the flow of goods (UNCTAD secretariat, 2014, 2). A crucial component of global trade is the ocean shipping, accountable for around 90 percent of worldwide traded goods (OECD, n.d.). The ocean shipping logistic is made from interconnected ports. These ports serve as nodes in maritime supply chains and are thereby the gateway to global trade (Alamoush, *et al.*, 2021, 1-2). The busiest and largest ports today handle millions of containers every year. Trading volumes that are predicted to rise as demand for global freight increases (World Shipping Council, n.d.; OECD, n.d.).

Ports can be divided into various operations based on the cargo it handles. This includes containers, liquid bulk, dry bulk, dry breakbulk, liquefied natural gas and liquefied petroleum gas (United Nations, 2022, XVIII & 9-13). However, ports are today often not limited to one type of cargo, instead they handle a variety of cargo. These ports divide the different types of operations by having dedicated areas where each cargo is handled. These areas are referred to as terminals. Firstly, container terminals are designed to handle containers being shipped by container vessels. These terminals are equipped with cranes and vehicles to handle the large number of containers being loaded and unloaded. Containers are usually measured with the unit referred to as twenty-foot equivalents (TEUs) (IContainers, 2019; Naturvårdsverket, 2003). Further, Roll-on Roll-off terminals are specialised towards handling wheeled cargo and therefore have ramps allowing cargo to be transported directly off and onto the vessels. Dry bulk terminals meet the needs of dry unpacked goods, such as gravel and coal. Further, liquid bulk terminals handle vessels carrying liquid cargo such as chemicals or oil. These ports use pipelines and cisterns for loading and unloading. Finally, passenger ports serve the purpose of transporting people (Naturvårdsverket, 2003).

The transportation and handling of cargo are essential to the port's operations, and cargo handling vehicles play a vital role in these processes. However, as these vehicles usually run on fossil fuels, they have a negative impact on the environment. In order to meet the climate goals defined in the Paris Agreement, ports need to search for alternative ways to fuel their vehicles (United Nations, 2022, XXVII). A potential approach to address this is to transition to a fleet powered by electricity.

1.2 Purpose

The purpose of this thesis is two-folded. Firstly to examine what factors to consider when implementing an electric road system in ports. Secondly to examine how these derived factors differ between different ports.

1.2.1 Research questions

Based on the presented purpose, this thesis can be divided into two main research questions:

RQ1: What factors need to be considered when implementing an Electric Road System in a port?
RQ2: How do ports differ in terms of how suited they are for an Electric Road System implementation based on the identified factors?

Answering RQ1 is necessary to be able to identify differences between various ports and thus to be able to answer RQ2, linking the two research questions to each other.

1.3 Problem discussion

While exploring opportunities to commercialise its technology, Elonroad recognised the closed-looped transportation system of ports as an interesting market. A large-scale deployment of an ERS in an open-looped transportation system, such as a public road network, implies an increased complexity as different brands and classes of vehicles, charging requirements, communication protocols and ERS systems must be able to function within the same space (Bateman *et al.*, 2018, 17). In contrast, deploying an ERS in closed-looped transportation systems involves less complexity, since vehicles generally travel along fixed routes separated from the public. Additionally, the need for interoperability is reduced, gaining operators more control of vehicle movements within the closed-looped transportation system. By analysing ERS deployment in a closed-looped transportation system, ERS can be seen as a complete solution, providing more of an overall view of the performance and impact of the ERS. Given the less complex nature of implementing an ERS in a closed-looped transportation system, makes an initial commercialisation of this novel technology more favourable to do in this type of system (Bateman *et al.*, 2018, 17). Several projects are today being conducted to test the feasibility and possible outcomes of different ERS solutions. Most of these projects are conducted on freight transports on public roads, thus focusing on open-looped transportation systems corresponding to no fixed routes or predetermined types of vehicles (Gustavsson, *et al.*, 2020, 4-5). In contrast, there are limited research and ongoing projects on how ERS could be deployed in closed-looped transportation systems, such as in ports. This increases the relevance of this thesis, as it has the potential to cover new grounds within the area of commercialising an ERS.

Further, implementing an ERS in the closed-looped transportation system of ports will be affected by several factors which will vary between different systems. This opens for comparison between different ports on which one is best suited for an implementation of an ERS. However, there is currently little to no research covering what factors to consider when implementing an ERS and no structured ways of comparing various ports based on these factors. This thesis intends to also address this problem and contribute by identifying these factors and developing a methodology to compare different ports to each other.

1.4 Delimitations

Without delimitations in this study, linking the two previously unrelated topics of ERS and ports together may result in the scope of the study becoming too extensive. Therefore, by including delimitations, the scope of the thesis can be kept at a feasible level, enabling the results to be sufficiently profound and tangible.

The first delimitation introduced was related to various types of port operations that exist depending on the type of goods handled. This thesis was delimited to mainly focus on one type of port operation, namely container handling terminals. Given the significance of container handling operations for the global economy and Elonroad's specific interest in this area, it was deemed particularly relevant to concentrate on this type of operation. Additionally, as the thesis was made in collaboration with Elonroad, this research was delimited to mainly study the conductive charging ERS technology attached to the road that Elonroad develops. The final delimitation was that it primarily focused on the commercial aspects and not the technical aspects. Although technical elements were addressed, it was assumed that the technology will function as intended.

1.5 Target group

The target group of this thesis can be divided into two main segments. The first segment refers to the management team of Elonroad and similar ERS developing companies. This target group can use this thesis' findings to identify and prioritise market opportunities within container terminals and similar port operations. The second targeted segment of this thesis are ports having container handling operations. They will be able to assess and compare how suited they are to implement and utilise an ERS in relation to other ports having container handling operations. They can use the findings of this thesis to evaluate their specific requirements and possible effects of implementing and utilising an ERS in their operations compared to competing ports. These insights can also be applicable to other cargo handling operators in a port since container handling operations have several similar attributes to other port operations.

1.6 Thesis outline

Chapter 1 Introduction - The introducing chapter provides the background context, purpose, and scope of the thesis. The two main research questions, RQ1 and RQ2, are also introduced along with a problem discussion and the delimitations of the study.

Chapter 2 Methodology - In the second chapter of the thesis, the methodological framework used in the study is presented. This includes a presentation of the research purpose and the decisions made regarding research strategy, research design and data analysis. The chapter also illustrates the work process and includes a discussion on the quality of the research.

Chapter 3 Literature review - Chapter three serves two primary purposes. Firstly, investigate what has been concluded by prior research in the field of sustainable transport, implementing an ERS and port operations. Secondly, it provides the theoretical foundation used to analyse and discuss the research findings.

Chapter 4 A current overview of container terminals and ERS - The chapter provides a current overview of container terminal operations and of the ERS technology based on findings collected throughout the interview study and the secondary data gathering.

Chapter 5 Analysing an implementation of a conductive road-attached ERS in a container terminal - The information presented in chapter 4 along with the theoretical foundation provided in chapter 3 are analysed in this chapter. Firstly, additional delimitations and assumptions, necessary for subsequent stages of the work process, are defined. Thereafter, based on the findings, three overarching areas of consideration when implementing an ERS in a container terminal are presented.

Chapter 6 ERS compatibility framework for container terminals - Using the analysis performed in chapter 5, a framework was created in this chapter which included all aspects worth considering when assessing the suitability of a container terminal to adopt an ERS. This framework was the foundation for creating a tool used for assessing and comparing the compatibility of an ERS in various container terminals.

Chapter 7 Tool pilot test - In this chapter, a pilot test of the tool developed in chapter 6 was carried out. The pilot test aimed to demonstrate an example of how the tool can be used, how information can be collected from different public and private sources, and how the tool's generated results can be interpreted. Thus, the pilot test displays the tool's abilities, while also providing insights into the tool's strengths and weaknesses, enabling for identification of opportunities for improvement.

Chapter 8 Tool pilot test discussion - This chapter discusses the use of the tool during the pilot test. Key takeaways are presented along with suggested tool improvements and possible application areas.

Chapter 9 Conclusions - The final chapter concludes the thesis by answering the research questions. It also highlights the theoretical and practical contributions of the research, limitations and suggestions for further research.

2 Methodology

In the second chapter of the thesis, the methodological framework used in the study is presented. This includes a presentation of the research purpose and the decisions made regarding research strategy, research design and data analysis. The chapter also illustrates the work process and includes a discussion on the quality of the research.

2.1 Research purpose

Research can have several different purposes depending on the aspired objectives and the characteristics of the study. Studies are typically categorised into four general groups based on the purpose of the study. These are descriptive, exploratory, explanatory, and problem-solving research. Descriptive research aims to identify and explain how something works. Exploratory refers to the objective of gaining an in-depth understanding of an object, process, relationship or similar. Explanatory research has the main purpose of seeking to interpret causation and its underlying reasons. Finally, problem-solving research is rather self-explanatory as it involves solving an identified problem (Höst *et al.,* 2006, 29-30). This thesis was structured based on both an exploratory and problem-solving research purpose. Exploratory as the purpose of this thesis strives to investigate the relationship and dynamics between two previously unrelated topics of ERS and container terminals. Further, problem-solving as the thesis addresses the difficulty of identifying the most suitable ports for implementing an ERS.

2.2 Research strategy

2.2.1 Qualitative vs. quantitative approach

Research can also be classified based on the format of the collected data in the study, as this format requires the use of different analysis methods. The two most commonly used approaches are qualitative and quantitative research. The major distinction between these is that qualitative research uses words, descriptions and visual images as the foundation of the analysis. Quantitative research instead consists of analysis based on numbers that can be calculated or classified (Höst *et al., 2006,* 30; Denscombe, 2010, 237). This difference makes the approaches suitable for different situations. Qualitative tends to favour small-scale projects as the data is mostly related to deep analysis and detailed descriptions. Therefore, researchers work closely with the data to develop a familiarity that facilities the conduction of analysis. By contrast, quantitative research is more appropriate when it comes to large-scale studies as it often involves data characterised by greater quantities. The quantitative format of the data allows for a large quantity of data to be collected, interpreted and analysed easier compared to the qualitative data which are in need of more in-depth analysis to grasp the ambiguousness of the concepts (Denscombe, 2010, 237-238; Saunders et al., 2007, 472).

An additional differentiation can be made regarding the level of involvement in research. Qualitative studies require the researcher to actively construct the data, as the studies might lack standardised research instruments, making the influence of the researcher more significant. Quantitative research on the other hand, is often associated with a lower likelihood of researcher influence due to its numerical nature, which leads to the collected data being perceived as more objective. (Denscombe, 2010, 237). Another dissimilarity between the two approaches is the timing of the analysis. For qualitative studies, the analysis often takes place during the data collection process. In contrast, the data analysis of quantitative studies is performed after the collection. This since quantitative studies often require many steps of interpretation and evaluation before it is possible to reach a conclusion. Qualitative, on the other hand, allows the researchers to expand their knowledge and draw conclusions during the process of the collection of data (Denscombe, 2010, 238-239).

This thesis adopted a qualitative approach as this provided more detailed descriptions and a deeper understanding which was necessary to answer the thesis research questions. The qualitative data collection resulted in an in-depth analysis of how the two previously unrelated topics could be connected to each other. The qualitative approach also allowed for the data to be interpreted and analysed simultaneously as being collected, allowing for redirection of focus as new insight emerged.

2.2.2 Primary vs. secondary data

In addition to categorising collected data based on its format, it can also be classified as either primary data or secondary data. Primary data corresponds to the information gathered specifically for the purpose of the report, which can be described as newly generated data. In contrast, secondary data refers to the collection of already existing data. This includes a wide range of materials such as reports, payroll details and various documents with statistics (Saunders *et al.,* 2007, 246-247).

This thesis included both the collection of primary and secondary data. A first round of data collection consisted of both reviewing current literature which constitutes secondary data, and conducting interviews in order to gather primary data and gain a nuanced perspective of the two previously unrelated topics. Later in the work process, the pilot test of the developed tool required another round of data collection. The data obtained in this round was also of both primary and secondary nature, collected from direct communication with previous interviewees as well as through accessing public databases.

2.2.3 Deductive vs. inductive reasoning approach

The concept of reasoning can be described through different principles with the three major ones being deduction, induction and abduction (Kovács *et al.*, 2005, 132-133). Induction refers to studies starting in a special case to then be able to draw conclusions on a general case. The special case is used to create theoretical ideas and conceive concepts which can then lead to implied results that potentially can be applicable on a widespread scale. Deductive, in contrast, is adopted in situations starting in a general case and moving towards fulfilling specific conclusions. This is done by using pre-existing concepts and theoretical ideas which are compared to observed results to demonstrate whether the pre-stated conclusions are verifiable or should be falsified (McCartan *et al.*, 2016, 19-20; Timmermans *et al.*, 2012, 171). Lastly, abductive reasoning merges inductive and deductive approaches to overcome the disconnection between theory and research. This through applying a new set of empirical observations and hypotheses that can capture hidden effects and causes behind the results of existing theory. Consequently, this process enables the identification of the likeliest possible explanation (Timmermans *et al.*, 2012, 171; Kovács *et al.*, 2005, 135-136).

This thesis was considered to be inductive since the study attempts to draw general conclusions by studying a specific case. By examining one particular company's ERS technology and comparing this with one particular port operation, container terminal operations, one specific case is analysed. The analysis of this specific case will form the basis for drawing more generally applicable conclusions across all types of ERS technologies and port operations.

2.3 Research design

2.3.1 Case study

The most common approaches used when conducting research are the survey, the case study, the experiment and the action research approach. This thesis followed the characteristics of a case study. Case studies are characterised by being an in-depth study of one or more cases, from which conclusions can be drawn and applied in a more general context. The number of cases studied depends on the conclusions that the research aims to draw. Further, a case study contributes to achieving deep understanding and allows for a flexible approach, meaning that the design of the process can be altered over time. (Höst *et al.*, 2006, 33-34; McCartan et al., 2016, 150). While case studies are commonly associated with qualitative data collection, it is important to note that many case studies also incorporate quantitative components. Additionally, it is important to use multiple methods for data collection in a case study as this results in more nuanced findings of the studied phenomenon (McCartan *et al.*, 2016, 150-151).

A case study was considered appropriate for the research being conducted in this thesis. The research purpose required a deep understanding of the two previously unrelated topics. By studying one specific ERS technology developed by Elonroad and a limited number of container terminals, general conclusions were drawn on how an ERS could be implemented in a container terminal, and further in port operations. The case study approach also allowed for the qualitative interview process and secondary data collection to be changed and optimised over time when new insights emerged.

2.3.2 Data collection

2.3.2.1 Literature review

The literature review is one of the most essential parts when conducting a research as it demonstrates the current state of knowledge within the topic which is to be investigated. It highlights the limitations in the existing literature and thereby shows how a new study can contribute to the development of knowledge within the field. After completion, the research will be assessed in light of existing work in the field, and the importance of the findings will be determined by their capacity to cover new grounds (Saunders *et al.*, 2007, 54-55). A literature review can be based on sources in many different forms, such as books, articles or research reports. It is a key factor to search for relevant work rather than just creating a comprehensive presentation of the subject. Finding relevant work will help the researcher with the design, implementation and interpretation of the study (McCartan *et al.*, 2016, 52)

The process of a literature review is an iterative process as the relevant literature might change as new insights emerge. The first phase of the literature review therefore forms the initial foundation of knowledge for the thesis. Later on, when time clarifies problems and limitations, the literature review can be revised to contain more specific information. Moreover, the iterative process of identifying and incorporating new information can enhance not only the quality of the literature review, but also help refine research questions and objectives (Höst *et al.,* 2006, 59-69; Saunders *et al*., 2007, 56).

The literature review in this thesis was carried out in five subsequent steps, see *figure 2.1*. The first step was to identify the current state of knowledge regarding sustainability within the transport sector. Subsequently, the focus of the literature review was specified towards the electrification of the transport sector and further the electrification of one industry within the transport sector, the port industry. The scope of the literature review was further specified by examining the current state of knowledge on the electrification of ports using an ERS and the potential business model implications of such an implementation. The process involved the identification of multiple sources, which were evaluated based on their relevance to the thesis. Furthermore, the literature review underwent several iterations and revisions as new insights were acquired and updates became necessary. The sources of information were mostly obtained from the databases LUBsearch and Google Scholar, although some literature available at the Lund University library was also utilised.

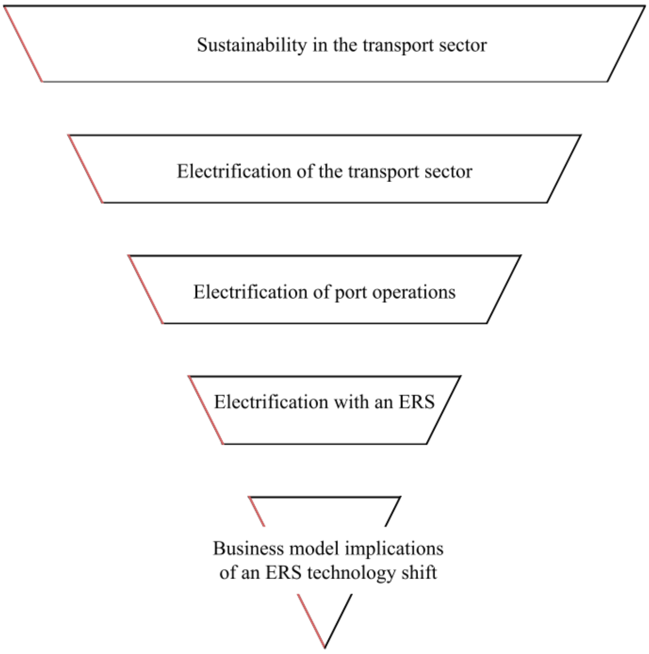


Figure 2.1: The process of the literature review

2.3.2.2 Interviews

In this thesis, interviews were the main method for collecting primary data. It was a time and resource effective way of gathering reliable, relevant and valid data (Saunders *et al.,* 2007, 310). Furthermore, it allowed for flexibility in the collection process since follow-up questions could be used to clarify and gain a more profound understanding of the interviewee's responses. This method was most suited when exploring complex topics and subtle phenomenons, where an in-depth understanding and analysis are required (Denscombe, 2010, 174-175). The data gathered from the interviews was used to compile the current situation overview of container terminals and ERS, which in turn served as the foundation for identifying the most important factors to consider when implementing an ERS in a port.

Interviews are usually divided into three different types based on the extent to which they are formalised and structured. The three types of interviews are categorised as structured, semi-structured and unstructured interview. Structured interviews utilise predetermined questionnaires and are typically linked to quantitative research, as they provide favourable conditions for gathering quantifiable data. For qualitative research, semi-structured and unstructured interviews are seen as better suited as these do not follow a predetermined structure and are thereby adaptable to the context. Semi-structured interviews are conducted by preparing general themes that the interview aims to cover, which might vary between occasions. Questions in this type of interview can be omitted or added during the interview, allowing the interviewer to steer the discussions in the optimal direction for the study. Finally, unstructured interviews correspond to an informal instance where there are no predetermined questions. However, the interviewer must decide in advance which aspects are to be brought up for discussion (Saunders *et al.,* 2007, 311-312)

During the first set of interviews completed for this thesis, a semi-structured approach was used. The underlying reasons for this interview strategy were linked to the explorative and problem-solving nature of the study. This approach allowed for broad topics to be covered while simultaneously being provided with an in-depth understanding. The flexibility of semi-structured interviews, also allowed for the uncertainty of not knowing the level of knowledge possessed by the respondent to be addressed, as the interview could be adopted while being conducted. However, numerous fundamental discussion topics were prepared beforehand to optimise the utilisation of each interview, thereby ensuring maximal primary data collection. The second round of interviews was conducted later in the study when doing a pilot test of the developed tool. These interviews adopted a structured approach as the data needed to be collected consisted of specific data points. Therefore, a predetermined set of questions were used. These interviews were conducted either via email or via telephone contact as the questions were straightforward and no additional discussion was deemed necessary.

The strategy related to the selection of which experts to interview in the study was important to ensure the validity of the research. Respondents were chosen based on the characteristics of the research questions, therefore ensuring their relevance and their capability to contribute with insights and deeper understanding. The two primary sampling strategies are purposive and random selection. The purposive strategy refers to the selection of individuals, organisations, or groups that can provide the greatest amount of information related to the objectives of the research. This strategy is often employed in qualitative research as it establishes favourable conditions for identifying pertinent data. Random selection, corresponding to every sample having the same probability of being selected, is on the other hand not so common in qualitative research (Devers *et al.,* 2000, 264-265)

The strategy in this thesis aligned with the purposive strategy, where respondents being capable of providing the most valuable insights were prioritised. Since two unrelated topics were to be investigated, it was necessary to establish two distinct approaches for identifying respondents. Elonroad served as a starting point for gaining an understanding of the ERS technology since it allowed the selection of relevant individuals within the organisation. To then obtain a more nuanced understanding, additional experts were selected outside of the Elonroad organisation. For container terminals, the goal was to identify respondents holding a management position within the container terminal to gain a broad understanding of its operations. Additionally, container terminals of different sizes and from various locations were chosen to obtain more nuanced data. Information regarding container handling vehicles proved to be particularly difficult to collect from the initial set of respondents.Therefore, additional, more specific interviews had to be held with experts on this subject as well.

The process of contacting relevant participants was two-fold, being based on both contact information found on the container terminal's communication channels and through Elonroad's network of contacts. In addition, to confirm the suitability of the interviewee, an interview guide was provided in advance, enabling the participant to review the interview guide and confirm their ability to respond to the suggested subjects. All interviews were conducted online either through Google Meet or Microsoft Teams, and lasted approximately one hour each. Apart from the interview occasions, some further communication was held through email to clarify or elaborate on earlier held discussions. All persons interviewed in this thesis are shown in *table 2.1*.

Table 2.1: The list of all interviewees for this study

Organisation	Name	Title
ATS & PSA, Port of Antwerp	Bart Paijmans & Toon van Boxelaere	Sustainability Manager & Sustainability Engineer
Bremenports Int.	Lars Stemmler	Head of Bremenports Int.
Elonroad	Anna Palmqvist	Queen of Production
Elonroad	Anton Torstensson	Vice President Business Development & Strategy
Kalmar	Per-Erik Johansson	Technology Manager Electrification
Lund University	Mats Alaküla	Professor, Industrial Electrical Engineering and Automation
N.C. Nielsen	Per Löthner	Regional Manager, Sweden
Port of Gothenburg	Cecilia Magnusson	Chairman of the Board
Port of Helsingborg	Christina Argelius	Chief Technology Officer
ITS, Port of Long Beach	Halfdan Ross	Chief Project Officer
The Swedish National Road and Transport Research Institute	Björn Kalman	Head of Research, Road and Rail Engineering
The Swedish National Road and Transport Research Institute	Henrik Sjöstrand	Senior Researcher

Some of these respondents were at a later stage contacted again to undertake a second interview when conducting a pilot test of the developed tool. These participants were selected due to the establishment of prior communication, which facilitated the communication for subsequent interviews. Further, during the initial set of interviews, participants were queried regarding their willingness to partake in a second round of interviews. This round of interviews was conducted either through email or telephone communication. The interviewees for the pilot test are shown in *table 2.2*.

Table 2.2: The list of interviewees for the pilot test

Organisation	Name	Title
ATS & PSA, Port of Antwerp	Bart Paijmans & Toon van Boxelaere	Sustainability Manager & Sustainability Engineer
Port of Helsingborg	Christina Argelius	Chief Technology Officer
ITS, Port of Long Beach	Halfdan Ross	Chief Project Officer

2.3.2.3 Complementary secondary data collection

To extend the scope of data collection, this study incorporated supplementary secondary data sources outside of scholarly literature and primary sources. This included sources such as websites, government publications, public databases and newspapers. Incorporating this type of data provided the study with a nuanced data set that strengthened the findings, presented alternative points of view and highlighted relatedness between different sources (Denscombe, 2010, 216-219; Saunders *et al.,* 2007, 248). One of the primary advantages of utilising this form of secondary data is the convenience and accessibility often linked to collecting this data, as researchers typically only need to access the material online or via a library (Denscombe, 2010, 220).

Secondary data in this thesis were used on various occasions in the study to supplement the literature review and the primary data collection. For example, Swedish government publications examining the potential of an ERS in Sweden were especially used to understand the ERS technology. Another example when secondary data was used was when examining how various container terminals were governed and managed. The World Bank's public database was particularly advantageous as a source of secondary data in this case.

2.4 Data analysis

Analysing the collected data is an important aspect of all theses, as it involves combining the theoretical framework with the empirically collected information to reach conclusions (Alvehus, 2019, 106). Due to the novelty of the field and the research question's nature, most of the data collected was qualitative. Although this study primarily consisted of qualitative data, it incorporated some quantitative elements when developing the tool and when conducting the pilot test of the tool. Additionally, a modified version of the PESTEL framework and the SWOT analysis framework were used to analyse and compile the collected data.

2.4.1 Qualitative data analysis

The qualitative data analysis of this thesis was based on the theory presented by Saunders, Lewis and Thornhill (2007, 470-508). The analysis was drawn upon the findings of the literature review, which established an initial foundation of knowledge from which the main subjects of the thesis could be identified. These main subjects of the thesis contributed to the creation of an interview guide with clearly defined topics to discuss during the interviews. During the interview process, additional overarching subjects became apparent, which were added to the list of main subjects of the thesis. The data collected from conducted interviews were coded and unitised into a common format which was then categorised into one of the many identified subjects of the thesis. This process of organising the data facilitated the identification of relationships and patterns between different subjects which constituted the foundation of the discussion and conclusions drawn. Further, a critical aspect considered when using this approach was to repeatedly verify that statements were confirmed by two or more independent sources, thereby enhancing the trustworthiness of the collected data.

2.4.2 A modified version of the PESTEL framework

To effectively achieve a comprehensive understanding of how a container terminal operates, a modified version of the PESTEL framework was used to summarise all the key takeaways. This section begins by presenting the theory of the PESTEL framework, followed by descriptions of how the framework was used and modified in this study.

To fully understand the environment in which the business operates, there are several perspectives to take into consideration. One of these is the macro-environment, which also corresponds to the highest-level perspective. This level consists of creating an understanding of the overarching trends that can have an impact on all types of businesses. To visualise and divide these trends up into factors, the PESTEL framework can be introduced. The PESTEL framework is based on the categories political, economic, social, technological, environmental and legal. These categories allow for key drivers affecting the business to be identified and analysed. Pinpointing these key drivers and their implications can help an organisation understand the intercorrelation between different identified key drivers and understand which of these will have a significant impact on the business' success (Johnson *et al.,* 2009, 25-27). However, there are some limitations with the framework as it is based on a holistic view through qualitative analysis, making the tool lack the further steps of quantitative measurements and evaluations (Yüksel, 2012, 53). Political factors encompass the regulatory impact a government can have, including areas such as policies and taxation. Economic elements influence the business' financial performance through for example growth and exchange rates, business cycles, employment and commodity prices. The social factors refer to anticipating and understanding of changing trends with regard to cultural and demographic aspects. Technological factors assess the existence of innovations that are changing the macro environment, including technological penetration, development and research. Environmental factors consist of the environmental issues and challenges an organisation has to deal with, such as emissions and waste. Finally, the legal factors identify the relevant laws and regulations, including safety laws, and environmental regulations (Johnson *et al.,* 2009, 25-27).

In this thesis, the framework was employed on a broader perspective covering an entire industry, container terminals, rather than focusing on a specific business within it. The model was used because of its ability to encapture several relevant perspectives necessary for doing an in-depth description and analysis of container terminal operations. However, the original version of this framework was revised to include an internal perspective, in addition to the external perspective. This facilitated a more profound understanding of the operations within the industry and the internal trends that prevail within it. Additionally, a modification was done by replacing the technological aspect of the model with the more comprehensive operational aspect, renaming the model PESOEL. This was done to create an even better understanding of not only the external drivers that affect a container terminal today but also the internal activities and functions that make up a container terminal's operations. Moreover, technology plays a significant role in all types of businesses and operations today, indicating that the operational aspect of the modified framework also entails technological considerations to some extent.

2.4.3 The SWOT analysis framework

To effectively achieve a comprehensive understanding of the ERS technology and its comparative advantages and disadvantages over competing solutions, the SWOT analysis framework will be used to summarise all the important points of comparison. This section begins by presenting the theory of the SWOT analysis framework, followed by descriptions of how the framework will be used in this study.

The SWOT analysis, representing strengths, weaknesses, opportunities and threats, is a framework used for summarising strategically important perspectives of an organisation. The aim of this approach is to evaluate to what extent a business is capable of handling its strengths and weaknesses, and further, the relevance of making adoptions with regards to the findings within opportunities and threats. This is often performed in relation to competing companies rather than an absolute evaluation (Johnson *et al.,* 2009, 81). Through this, the SWOT analysis manages to capture both the external and internal environment of the company. The internal perspective is connected to strengths and weaknesses, including the capabilities, resources and potential outcomes existing in the current moment of the company. External features refer to the threats and opportunities being more difficult to control (Larsson *et al.,* 2022, 1109-1110). In the framework, weaknesses correspond to negative features that need improvement. Strengths refer to the positive features that distinguish the business from its competitors. Opportunities aim to highlight the openings that exist for the company to create additional competitive advantages or additional growth in the company. Finally, threats correspond to the risks that could hinder the current operations or counteract the organisation's growth (Sumo *et al.,* 2022, 29). The use of a SWOT analysis could help an organisation make priorities of resources and time by visualising current aspects affecting the business. However, there are two common pitfalls connected to using a SWOT analysis. Firstly, the assessment might generate extensive lists of the different strengths, weaknesses, opportunities and threats, thus priorities based on importance can be necessary to include. Secondly, it is important to avoid overgeneralisation to ensure that there is a complete understanding of the underlying reasons explaining a strength, weakness, opportunity or threat. It is essential to remember that the SWOT analysis is not a substitute for other analyses that could help clarify insights (Johnson *et al.,* 2009, 83).

In this thesis, the framework was not applied to a particular company but instead to a technology. The framework was used to summarise the effects and conditions of implementing a conductive road-attached ERS. The use of the SWOT analysis was divided up into multiple scenarios based on the different situations being apparent in the examined type of transportation system. The choice of the SWOT analysis was based on the framework's ability to serve as a basis for explaining the current situation of a relatively new and complex technology.

2.5 The process of the thesis

An overview of the thesis work is provided in *figure 2.2*, which illustrates how the different parts of the thesis were integrated and the sequence in which the process was followed.

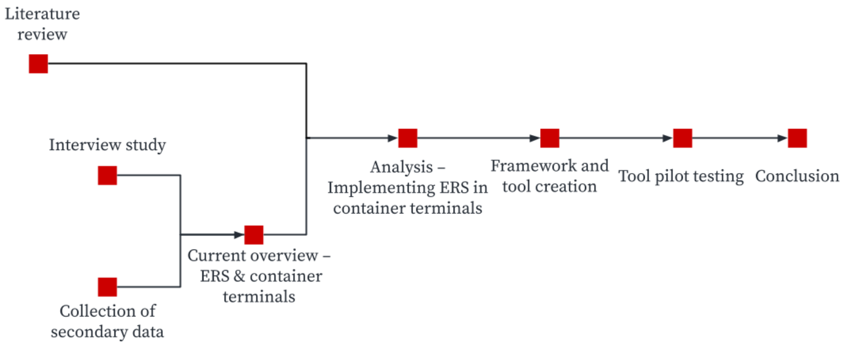


Figure 2.2: The process of the thesis

2.6 Research quality

Verifying the research in this thesis is an important step of the process to ensure that conclusions are well-founded, results are general and that the phenomenon studied is truly addressed (Höst *et al*, 2006, 41). This allows for increased research credibility and thus ensuring the quality of the work. The approach for evaluating the credibility of the research in this thesis is to analyse the validity, reliability, generalisability and objectivity of the study (Denscombe, 2010, 298).

Validity refers to the quality of the data, meaning its accuracy and precision to capture the intended subjects (Denscombe, 2010, 298). The data collection for the literature review of this thesis prioritised sources being peer reviewed and being recently published as information in this novel field can quickly become outdated. However, some sources consisted of information where little to no change has occurred since the article was published. In these cases, older sources were considered acceptable to use. Additionally, all collected data were checked against several different independent sources to ensure the validity of the information. The remaining secondary data that was collected underwent validation through similar approaches, however, as this data lacked peer review, an additional level of caution was exercised. The information obtained from interviews is seen as thoroughly validated since the interviewees, who were not considered stakeholders in this thesis, had no apparent motive to provide invalid or biassed data. Additionally, the information provided by Elonroad regarding their developed technology had a risk of being somewhat biassed and overly enthusiastic. To address this risk, complementary secondary data was collected and external interviews were held to confirm and to nuance the data collected from Elonroad.

Reliability is whether the research instruments is neutral and consistent, meaning that other studies within the same topic would reach the same results. To achieve this, it is important to highlight and document the decisions and methods used in the study (Denscombe, 2010, 299-300). In this thesis, the methods used are clarified and visualised to allow readers to understand the complete research process. Additionally, all impacting decisions were stated and justified. Further, the interviews were all transcribed and the transcripts were saved as documents. Thereby the thesis is considered open for audit and the information provided is seen as enough to correspond to a reasonable level of reliability.

The third basis for judging the credibility is generalisability which is the research's ability to be applied to similar cases. This is especially important for case studies, as it is often questioned whether a small number of cases can represent a more general case (Denscombe, 2010, 300-301). Since this thesis constitutes an actual case study, the research aimed to maintain a general perspective while incorporating various nuanced perspectives. This was done by interviewing various independent individuals from different geographical locations and by using multiple secondary data sources. Furthermore, the collected data for the two previously unrelated topics covered in this thesis was handled separately in the initial stage of the data gathering process. This resulted in the findings being more easily applicable to other cases where only one of the two topics is intended to be covered.

The final aspect, objectivity, relates to if the thesis is influenced by bias or not. The researchers conducting the study run the risk of introducing bias, which could lead to the findings and conclusions becoming more subjective. It is therefore important to ensure that the researchers maintain a transparent mindset throughout the study (Denscombe, 2010, 301-303). To ensure an absence of bias, this thesis collected data from various primary and secondary data sources. Further, the study aimed to provide multiple perspectives in all cases, which resulted in nuanced findings and the prevention of conclusions being affected by biases.

3 Literature review

Chapter three serves two primary purposes. Firstly, investigate what has been concluded by prior research in the field of sustainable transport, implementing an ERS and port operations. Secondly, it provides the theoretical foundation used to analyse and discuss the research findings.

The literature review provides a critical analysis and synthesis of existing research and scholarly works relevant to the electrification of ports and the use of an ERS. Through a thorough review of the literature, this section aims to contextualise the research purpose and identify gaps, limitations, and areas for further investigation. The review covers mainly theoretical studies, including peer-reviewed articles, books, and other academic sources. The goal of this literature review is to establish the theoretical framework and research context for the study. The literature review starts with an introduction to the sustainability developments of the transport sector, followed by how this sector can be electrified, with a particular emphasis on electrifying maritime ports. Lastly, the review provides insights into how a vehicle fleet can be electrified with an ERS and its business model implications for ports.

3.1 Sustainability in the transport sector

The transportation sector is considered to play a vital role in today's socioeconomic development. By allowing for improved mobility and accessibility, people are provided access to education, services, goods and employment, thus improving the prosperity of society (Czech *et al.*, 2022, 1-3). However, sustaining the prosperity of this important industry has proved to be difficult, as more detrimental aspects of the transportation sector have been highlighted, proving to have multiple negative societal impacts (Illahi *et al.,* 2021, 1-2; Czech et al., 2022, 1-3). Environmentally, the transportation sector's adoption of fossil fuels has resulted in climate change and impaired qualities of air, water and soil. Socially, transportation emissions have led to respiratory and cardiovascular diseases, allergies and premature deaths to become more frequently occurring. In economic terms, global costs for health damages from air pollutants alone correspond to billions of dollars annually (de Freitas *et al*, 2022, 2). Therefore, it is important to not only maximise the benefits the transport sector contributes with, but also minimise the negative effects this industry causes to society. This requires the optimisation of the transportation system to be done in a sustainable way, considering all three pillars of sustainable development. These are the environmental, the social and the economic pillar of sustainability (Illahi *et al.,* 2021, 1; Dimmet, 2022, 3-4).

The role of transportation in the development of a sustainable future was first recognized in 1992 at the UN's Earth Summit in Rio de Janeiro (United Nations, 1992, 18-31). From then on, the attention to sustainable transportation has increased. The latest global agenda, the *2030 Agenda for Sustainable Development*, explicitly emphasises the importance of sustainable transport systems. Key to this agenda was the formation of the 17 Sustainable Development Goals (SDG), functioning as an action plan from 2015 to 2030 in areas of critical importance for the planet (United Nations, 2015, 17-32). An examination of the SDGs highlights multiple overall targets stretching across the 17 different goals. Transportation plays a substantial role in five of these overall targets: security, digital technology development, decarbonisation, supply chain optimisation and transport accessibility. Based on the frequency of which these overall target schemes occur in SDGs, transportation seems to play a key role in SDGs 7, 9, 11, 12 and 13 (Ross *et al.*, 2020, 622-627; Dimmet, 2022, 4-6). SDG 7 sets the goal of ensuring access to affordable, sustainable and reliable energy for all. Improvement of global energy efficiency is one key topic in this goal, where the transport sector, as a big energy consumer, plays a major role. SDG 9 aims to build a sustainable and resilient infrastructure to support economic growth while allowing affordable access for all. Similar concerns are addressed in SDG 11, where the aim is to ensure access to sustainable, safe and affordable transport systems for all through the development of improved public transport systems. Lastly, SDG 13 requires urgent action to counteract climate change and its impacts, which is highly relevant for the transport sector (United Nations, 2015, 17-32; Dimmet, 2022, 4-6). Being involved in multiple different SDGs emphasises the importance of sustainable improvements in the transport sector in the development of a sustainable future.

3.2 Electrification of the transport sector

One approach to reduce the environmental impact of the transport sector is to initiate a conversion towards electrification. In today's research, the shift towards EVs within all types of operations is seen as one of the most important and promising developments in the transition towards alternate sources of energy (Dimmet, 2022, 14). The contribution to decarbonisation is considered one of the main reasons for electricity to be considered an increasingly relevant alternative fuel. Studies have shown that EVs have the potential to substantially reduce the emission of CO_2 (Caltabellotta *et al.,* 2021, 12). Further, the acknowledgement of EVs has arisen from the fact that even though extensive developments in diesel engine technology have been made, the results still haven't reached sufficient decreases of emissions (Hämäläinen *et al.*, 2020, 220). This has contributed to a realisation that the world is in need of bigger and more drastic changes, having made higher bodies of governance begin to act. The introduction of emission reduction targets is now seen at local, national and supranational levels. Recently, the European parliament announced a new set of regulations, requiring new cars to have net-zero CO_2 emission by 2035. This is one step towards achieving the long-term goal of climate neutrality by 2050 set by the European Commission (Cabrera Serrenho *et al.,* 2022, 1-2). Similar targets have also been addressed by the UN, which is putting pressure on industrialised countries to comply with necessary requirements to tackle highlighted environmental challenges. These challenges have also reached the automotive industries that are now incorporating EV technology and pledging to start phasing out combustion engines. However, electrification of transportation is a far wider concept than only considering EVs. The transition requires an interaction of several activities (Bhaskar *et al.,* 2022, 231-232). One way to highlight this is by introducing the term electromobility which is defined as "a set of activities related to the use of EVs, as well as technical and operational EV solutions, technologies and charging infrastructure, as well as social, economic and legal issues pertaining to the designing, manufacturing, purchasing and using EVs" (Macioszek, 2019, 1). This definition emphasises the complexity of electrifying transportation.

From an environmental perspective, an electrification of the transport sector would significantly lower the sector's emissions of greenhouse gases, air pollutants and noise (Mutter *et al.,* 2022, 12). However, this is based on the condition that the electricity that drives the vehicles is produced in a sustainable way. Today, countries have various ways of producing electricity, creating different carbon footprints. Therefore, the environmental impact of electric transportation is heavily reliant on whether the electricity is obtained from renewable energy. Only when the electricity is generated from renewable sources and the carbon footprint is minimised, can the use of EVs be considered climate neutral (Caltabellotta *et al.,* 2021, 12*)*. Numerous countries still rely substantially on coal power to generate electricity, which is hindering an electrification in these countries from achieving its full potential (Wiedmann *et al*., 2017, 538). Further, another often discussed topic concerns the production of the batteries used in the vehicles. This production requires the use of scarce metals and requires large amounts of energy, not necessarily sustainably produced. This highlights the importance of not analysing the actual use of the battery, but the entire life cycle of the vehicles when determining the sustainable impact of an EV compared to a combustion engine vehicle. By taking a life cycle approach, one can observe that EVs with batteries have a comparable impact of around 60 percent compared to an internal combustion engine vehicle of the same size (Caltabellotta *et al.,* 2021, 11-19).

From an economic perspective, EVs have a higher purchasing price while having a shorter driving range compared to a diesel-driven equivalent. Additionally, there is still a lack of sufficient charging infrastructure in parts of the world for EVs, making them economically less attractive (Hämäläinen *et al.*, 2020, 220). To fully electrify the transport sector, expansions of current charging infrastructures are required to face the rapidly increasing demand for vehicle charging resulting from the growing EV market (Allen *et al.,* 2022, 1-2; AbelWahed *et al*., 2021, 401-404). The increased number of EVs will strain the electricity grid as people tend to follow similar routines and thus, want to charge at similar times (Hsu, 2022, 22). Public governance is one force of great importance in the development of a sufficient charging infrastructure, being influential in several parts of the development process. This stakeholder is involved in the planning of projects and investments, the creation of initiatives, legislation and policies, the allocation of resources and in the generation of long-term visions (Ruggeri *et al.,* 2020, 2). Another economic aspect worth considering is that an adoption of electric transportation may reduce the dependency on foreign oil for countries having to import fossil fuels. This can lead to a more stable and secure energy supply for these countries and result in reduced vulnerability to fluctuations in global oil prices. It can also provide economic benefits for individuals, businesses, and governments by enhancing new possibilities of employment and revenue from being able to produce their own energy. However, the opposite implications might be found in countries being heavily reliant on the export of oil. (Iqbal *et al.,* 2021, 89417; Ali *et al.,* 2022, 2143-2144; Rajagopal, 2023, 1-2 & 7).

Socially, electrification will first and foremost improve the societal environment as it reduces pollutants, vibrations and noise. This is especially relevant in urban areas where the density of people is higher. However, there are safety risks connected to the use of EVs. There is a risk of failure of the batteries, more specifically, the risk of overheated batteries which can cause fires and emit toxic gases. Although the probability of this is low, regulations should be instituted to ensure that sufficient measures have been taken to avoid these types of unfortunate outcomes (Rodrigues *et al.,* 2022, 1-6). Today, the general acceptance and willingness towards EV solutions are increasing. People encourage sustainable solutions as there has been a spread of environmental awareness in the public. However, to achieve a fully successful adoption of EVs it is important that vehicle performance and price can reach sufficient levels and surrounding charging infrastructure can reach desirable levels (Ajmal *et al.,* 2023, 11969).

3.3 Electrification of ports

One of the areas of transportation that are looking for new innovative solutions to streamline their operations is ports used in maritime shipping. This sector is challenged by rising energy prices and is facing legal and societal pressures for sustainable transitions in order to reduce its impact on the environment which, in turn, has resulted in ports having to review their internal operational strategies. The maritime shipping sector represents almost 3 percent of the worldwide emissions of greenhouse gases, among which ports represent a substantial share. Ports are dependent on the use of fossil fuels in order to run their operations, resulting in ports being a major source of air pollution and CO_2. The carbon intensive port sector is therefore under critical pressure to environmentally improve its operations. Today this is done by introducing renewable energy to its operations, alternative fuels and integrating smarter systems for energy distribution and consumption. One approach for enhancing energy efficiency and improving environmental performance is by electrifying current cargo handling vehicles. The implementation of electric equipment has the potential of reducing the use of fossil fuels, which would result in lower greenhouse gas emissions and mitigate ports' overall impact on the climate (Çağatay *et al*, 2019, 170; Mueller *et al.,* 2023, 1-4). In today's operations, ports handle high quantities of cargo which requires many vehicles within the port, especially in container terminals where the containers are transported using several different vehicles. Due to these intensive workloads, operations are running on high levels of occupation resulting in vehicles corresponding to a large share of the energy used in a port. However, the consumption of energy varies depending on the intensity of which cargo arrives (Alikhani *et al.,* 2021, 1-2).

Presently, most activities in ports are driven by diesel and have the potential of being electrified. This includes the transportation of cargo within the storage yard, unloading and loading the vessels, and the refuelling of vessels. However, the process of electrification has progressively begun in ports. One example of this is the charging of ships with shore power which allow vessels to turn off their auxiliary diesel engines and instead rely on the energy supplied by the shoreside power grid (Zhou *et al.,* 2022, 1-2; Postelwait, 2020, 28-30). Another current initiative to electrify operations is the introduction of electric equivalents of current container handling vehicles. Rubber-tyred gantry cranes are one example of a vehicle becoming gradually electrified. In the absence of electrification, these vehicles run on diesel and therefore add to the CO_2 emission in container ports (Chen *et al.,* 2022, 2034-2036; Yu *et al.,* 2019, 552-554). Electrifying heavy-duty vehicles and vessels is a trend starting to become more popular as it is an effective way of reducing emissions and has the benefits of being quieter, cleaner, and cheaper. However, to utilise the full potential of these benefits, upgrading the grid capacity in ports will potentially be necessary (Zhou *et al.,* 2022, 2 & 7-8; Postelwait, 2020, 28-29). These upgrades and the increased demand for electricity will put pressure on the port's local power grid's ability to supply the necessary levels of electricity (Harnischmacher *et al.,* 2021, 145). To face this increased need for electricity that comes with an electrification of ports, smart planning methods are one tool that can be helpful. Smart planning would enable electrified processes to become more cost-effective and less demanding of the power grid. This is done by purchasing electricity at certain hours based on forecasting and by ensuring power supply peaks are kept at a minimal level (Alikhani *et al.,* 2021, 1-2).

Further, the shift towards electrification in ports will support the development of digitalisation and automation in ports. These three factors are all interrelated as digitalisation enables automation and electrification enables setting technical conditions that could accelerate the digitalisation. Jointly combined, they could help stakeholders to reach their objectives as they have the potential to increase both productivity and efficiency. This by eliminating the human factor and by allowing for increased availability of data that can be utilised in streamlining the port operations (Zhou *et al*., 2022, 1-3).

3.4 Electrification with an ERS

The adaptation of EVs is well underway but its uptake has been limited due to restricted battery ranges, high purchase costs and a lack of charging convenience. A relatively new approach to overcome these challenges is the ERS, a charging infrastructure connected to the road, allowing vehicles to charge their batteries while being in motion. This dynamic way of transferring electricity to EVs can be done both conductively and inductively, either through overhead transmission lines or rails attached to the road (Taljegård *et al.,* 2020, 606-607; Márquez-Fernández *et al*., 2019, 1-2).

Recent research has analysed the environmental, social and economic effects of a large-scale implementation of an ERS at various locations around the world (Shoman *et al.,* 2021, 2-3). The environmental benefits of an ERS are mostly connected to the benefits gained from transitioning from fossil fuel driven vehicles to EVs, resulting in reductions of noise, greenhouse gases and other air pollutants (Taljegård *et al.,* 2020, 612-615; Gustavsson *et al*., 2021, 37-41). Lower levels of air pollution also have a positive social impact on public health, as these small, emitted particles have several serious health risks (Gustavsson *et al*., 2021, 40). Economically, ERS allows for shorter required battery ranges, which in turn allows for economic savings as the sizes of batteries can be reduced. Furthermore, by distributing power to vehicles throughout the day, peak power grid consumption can be reduced (Shoman *et al.,* 2021, 15-17; Gustavsson *et al*., 2021, 37). However, there are some additional maintenance costs and several investment costs to consider, including the development of new electricity networks, supporting infrastructure components and the cost for the ERS itself (Taljegård *et al.,* 2020, 609; Gustavsson *et al*., 2021, 65-69). Several studies have been conducted trying to estimate the total investment cost and CO_2 mitigations of implementing an ERS infrastructure. The share of roads covered by ERS has a direct impact on the investment cost per kilometre and total CO_2 mitigations. For the conductive rail technology, research suggests that investment cost ranges from 400 000 $€_{2016}$ per kilometre to 1 670 000 $€_{2016}$ per kilometre based on different estimations of future costs. This rather large cost interval found in the literature is mainly because different ERS technologies have solely been studied in small-scale pilot tests at designated test sites and on short stretches of public roads (Taljegård *et al.,* 2020, 609-610). Including the number of vehicles using the ERS in the investment calculations, shows that the lowest investment cost per vehicle kilometre is for roads having high average daily traffic (ADT) (Taljegård *et al.,* 2020, 615-616). CO_2 emission decrease dramatically until the coverage of ERS reaches 40 percent of the total road length. A deep dive into the Norwegian and Swedish public road systems shows that covering 40 percent of all European and National roads in these countries would reduce emissions by 46 percent in Norway and 55 percent in Sweden for heavy vehicles. Additional increases in road coverage thereafter would not result in as high marginal CO_2 emission savings. Therefore, implementing ERS on the most heavily trafficked roads seems important for ensuring maximum efficiency from a CO_2 mitigation and lowest investment cost per vehicle kilometre perspective (Taljegård *et al.,* 2020, 612-615; Shoman *et al.,* 2022, 7-8).

The development, diffusion and success of this rather new technology is influenced by the complex system of multiple stakeholders. In general, the main stakeholders are the operators, the authority and the various suppliers of electricity, technology and road infrastructure. Examining the objectives and perspectives of the multiple stakeholders highlights that their primary concern with implementing an ERS is the financial and planning aspects. Further, stakeholders express a concern regarding the environmental aspects and the social implications of an ERS implementation, including additional safety risks and potential changes to the company image. (Wang, *et.al.*, 2019, 8-17).

3.5 Business model implications of an ERS technology shift

Technology shifts are considered a substantial threat to the existence of any established business. There are many historical examples of companies having technologies constituting their competitive advantage but later transforming into their primary disadvantage. These shifts have turned out to be profoundly difficult to manage, as changing one core technology for another has proven to be complex and resource demanding. Businesses in the transportation sector face the possibility of a significant technology shift with the emergence of ERS. Unlike traditional refuelling or charging solutions, ERS would introduce new interfaces, technologies, and stakeholders (Tongur *et.al.*, 2014, 525-534). Research suggests that problems linked to technology shifts are often related to a reluctance to adapt sufficient business models. Christensen (2006, 48) concludes that the primary challenge of implementing disruptive technologies is “a business model problem, not a technology problem”, emphasising that the main challenge is to adopt a sufficient business model fit for the technology shift. If successful, former adopted business models, hindering the adoption of technology shifts, can be avoided whereas new business models, essential for the value-capturing of the new technology, can be utilised (Tongur et.al., 2014, 525-534). As ports currently are majorly powered by diesel, an introduction of an electric charging infrastructure such as an ERS, will correspond to a significant technology shift. This technology shift would have a beneficial environmental impact as ERS can contribute to reducing emissions through electrification. Given the immense pressure on ports to reduce their operational emissions, an environmental agenda is likely to already be existent in port’s current business model. Furthermore, some ports have gradually started to introduce EV equivalents which further emphasises the existent commitment to reducing environmental impact. Therefore, an ERS technology shift for ports can be considered less significant as it would align with major parts of the environmental objectives already incorporated in the port’s current business models. (Çağatay *et al*, 2019, 170; Mueller *et al.,* 2023, 1-4; Zhou *et al.,* 2022, 1-2; Postelwait, 2020, 28-30).

4 Current overview of container terminals and ERS

The chapter provides a current overview of container terminal operations and of the ERS technology based on findings collected throughout the interview study and the secondary data gathering.

4.1 Current overview of container terminals

This section will provide an extensive understanding of the container terminal industry by covering the six aspects of the earlier presented PESOEL framework. The aspects will not be covered in the order of the framework since certain aspects are better suited as an initial introduction to the topic than others. Some aspects turned out to have similar conditions across all types of port operations, hence these are discussed with a more general perspective that encompasses all port operations and not only container terminal operations. Lastly, the key takeaways from this section will be presented in the PESOEL framework, see *table 4.2*.

4.1.1 Operational: Container terminal operations

Container terminals can vary considerably regarding their operations, properties and design. The characteristics adopted by a terminal depend on the capacity needed for cargo handling, which is in turn based on the country's overall demand for import and export. The dominant player in cargo handling is China, accountable for almost 40 percent of the container trade among the top 100 facilities worldwide. Additionally, China hosts the world's largest container port, the Port of Shanghai, having a throughput of approximately 47 million TEUs in 2021. To place this into perspective, the biggest container port in Europe, the Port of Rotterdam, had a throughput of 15 million TEUs. Solely the volume growth of TEUs handled in Shanghai from 2020 to 2021 represented a greater number than the annual throughput for ports such as Oakland or Gdansk (Lloyd's list, 2022, 4-5 & 24-25).

With regard to the quantity of containers handled, there are several aspects determining the throughput capacity of a port. Firstly, one of the most critical aspects is the availability of land, where more handled containers require more space for storage (UNCTAD, 2018, 75). Further, an underlying basic requirement for handling sizable shipments is the port's ability to receive large vessels. The biggest ships today have a capacity reaching over 20,000 TEUs and these vessels demand a certain fairway depth as they carry heavy weights. This depth is therefore a necessity for becoming a major competitor in the industry (McKinsey & Company *et al*, 2018:a, 20; Magnusson, 2023). The trend of vessels becoming bigger is present, putting pressure on ports to respond to these increasingly stringent requirements by streamlining the use of space, equipment, labour, services and technology (UNCTAD, 2018, 73-74).

There are two main categories of ports today. Some ports exclusively act as an operator for import and export of goods, while others have targeted the segment of transhipments, *see figure 4.1*. Transhipment refers to the process of preparing cargo for subsequent maritime transportation by unloading containers from one ship and then reloading them onto another vessel (Ross, 2023). A further distinction of container ports is underscored by the degree of operational intensity. Highly trafficked ports accommodate numerous vessels, resulting in substantial operational demands that necessitate continuous round-the-clock functionality. In contrast, other ports may not require the same tight schedule of activities as fewer shipments arrive (Paijmans & van Boxelaere, 2023). A final notable variation between ports concerns the level of automation. The automation can be applied to several processes and refers to both stacking and horizontal transportation. In today's industry, only a limited number of ports have incorporated automation to some degree, with only a handful of operators soon to reach fully automated terminals (McKinsey & Company, 2018b; Ross, 2023).

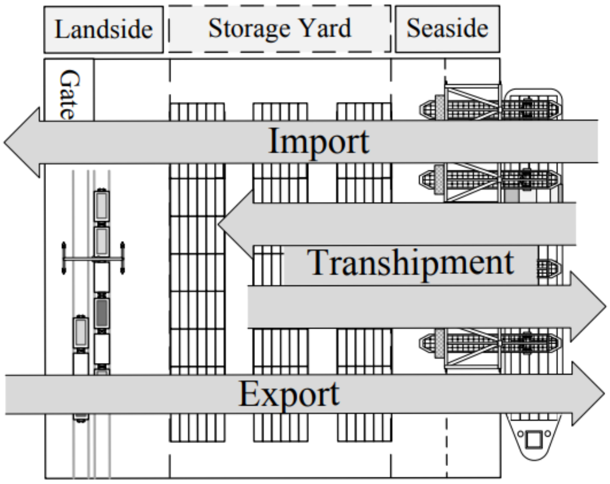


Figure 4.1: The main types of operations within a container terminal
(Wiese, 2012, 9)

4.1.1.1 Layout of a container terminal

Ports are today made up of terminals, with the size of a port being determined by the quantity of terminals comprising it. Each terminal is specified on a certain type of port activity, whereas one of these activities is container handling. For instance, the Port of Gothenburg operates several terminals, including one that is solely dedicated to container handling. In contrast, the Port of Antwerp comprises multiple container terminals inside the port. This port structure allows for activities and terminals to be operated by different actors. (Magnusson, 2023; Paijmans & van Boxelaere, 2023). Each container terminal needs access to a quay, storage yard, transportation routes and connection to intermodal traffic to run its operations. These parts of a container terminal can be summarised with the terms seaside, yard and landside, *see figure 4.2*. Seaside refers to the area encompassing the quay, including both quay wall with all its berths, quay cranes and apron. Yard specifies the area where containers are stored, and landside denotes the area where external traffic is connected. Among the described components existing in this three parted classification, the quay constitutes the process of unloading and loading a ship, involving specialised cranes and designated pick up points for internal vehicles. The storage yard serves as the repository for containers and is characterised by stacking arrangements that can vary in regards to both height and depth (Wiese, 2012, 8-13)

Seaside, yard and landside are all connected through an infrastructure of roads. The routes of these roads are designed to facilitate the movement of vehicles within the container terminal. The formation of the routes is optimised to allow for maximised productivity. These optimised routes include main roads where most vehicles travel, allowing for quicker and easier transportation. These main highways result in somewhat similar driving patterns for vehicles within the terminal (Ross, 2023; Argelius, 2023). Intermodal traffic refers to the complex system of interlinked external traffic, thereby allowing for a change in modes of transportation. To allow this flow of goods, container terminals can be connected to external roads and rails. The trucks and trains are loaded within the container terminal in the landside area (Magnusson, 2023; Ross, 2023). The different areas inside a terminal are considered permanent and not frequently rearranged as this would be a complex and time demanding activity. However, terminals can be flexible to some extent. In the Port of Antwerp for example, cranes used at the seaside are moveable and can be placed freely along the quay (Paijmans & van Boxelaere, 2023).

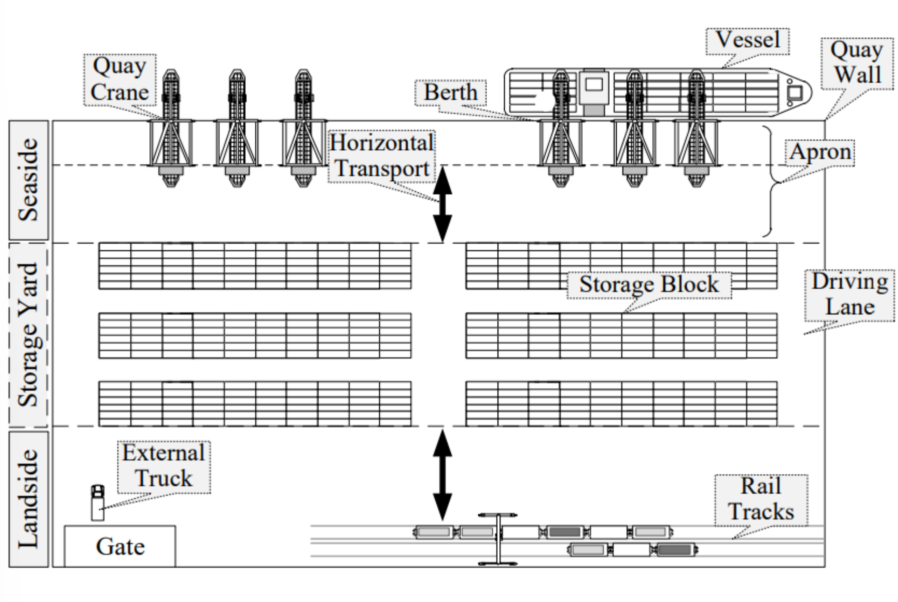


Figure 4.2: Schematic overview of a container terminal (Wiese, 2012, 8)

The key determinant for all the choices concerning the layout of the terminal is the amount of space on which the terminal operates. Nowadays, space is widely acknowledged as a valuable asset. An acknowledgement which has its roots in several factors and trends. Notably, as ports are often located in proximity to cities, they are constrained to a certain area and limited to managing their operations on their available land. Furthermore, as vessel sizes have increased, so have the quantity of arriving containers. This has pushed terminals to enhance their operational efficiency as the number of arriving containers increases while available land remains the same. At some locations around the world, land is an expensive resource, complicating the process of acquiring more land. In response to all these contributors, terminals are seeking innovative solutions to counteract the constant demand for expansion. These solutions include optimising stacking techniques using more efficient vehicles and machinery that enable tighter and higher stacking, and automation of current operations which can improve space efficiency (World bank, 2007, 76 & 97; Ross, 2023; Argelius, 2023; Stemmler, 2023).

4.1.1.2 The journey of a container

By examining the journey that a container undergoes, it becomes evident that the overall steps are typically structured in a similar manner. From an import point of view, the process begins with the arrival of a shipping vessel loaded with containers. Once the ship has berthed, most terminals use big cranes to discharge containers from the boat to the quay. Either by placing them directly on a transportation vehicle, or by placing them on the apron. Then, horizontal transportation is required to move the containers from the seaside area to the storage yard. The loading of a container onto a horizontal transportation vehicle can be categorised as either active or passive. Active technologies refer to vehicles that are able to lift the containers themselves, while passive ones need to be served by a crane or another vehicle. Once loaded on the vehicle, the containers are transported to a designated location at the storage yard. The containers are there stacked either directly by the vehicle itself or through the assistance of another vehicle or crane. The stacking is done by a vertical stacking vehicle placing containers upon each other in so called storage blocks which vary in height, depth and density. The container is then stationed in the storage yard until it is collected by a vehicle for further movement. This movement can be either back to the quay for transhipment or to external traffic for import. Containers being imported inland are either retrieved and loaded directly onto an external transport mode or moved horizontally to a predetermined loading point at the landside. At this loading point, containers are placed on either a truck or a train, for external transportation to the hinterland. To serve these external transportation modes, the landside operations use similar equipment as the storage yard. (Paijmans & van Boxelaere, 2023; Ross, 2023; Wiese, 2012, 10-19).

4.1.1.3 Vehicles used in container handling operations

Horizontal transportation and vertical stacking are terms widely used to categorise different vehicles. These terms symbolise which direction the container is moved. Horizontal transportation refers to the transportation of containers on ground level and vertical stacking indicates lifting processes. The container terminal operations require both types of vehicles to be present throughout the process. For a visual presentation of subsequently featured vehicles, *see appendix A.1.* Additionally, the presented features of the vehicles are summarised in *table 4.1.*

Studying horizontal transportation, one of the most commonly used vehicles is the terminal tractor. This vehicle shares similarities with conventional trucks used on public roads but the difference lies in the adoption towards designing it to suit the unique conditions of the container terminal environment. The terminal tractor is designed to facilitate the movement of containers from the quay to the storage yard. Thereby, the terminal tractor is intended for lower speeds and shorter distances than conventional trucks. The vehicle consists of a smaller driver's cab which is connected to a trailer onto which a container can be placed. The horizontal transportation nature of a terminal tractor means that this vehicle always requires the support of another supporting vehicle to be able to discharge and load containers. However, these features also allow for the terminal tractor to move flexibly within the container terminal and its lower performance compared to conventional trucks contributes to the terminal tractor being of relatively low cost (Johansson, 2023; Argelius, 2023).

Another frequently used vehicle for horizontal transportation is the automated guided vehicle (AGV). The AGV is used in the same parts of the process as terminal tractors, meaning that its main task is to transport containers from the quay to the storage yard. Similarly, as the terminal tractor, the AGV cannot lift any container by itself and therefore requires assistance from another vehicle. However, the AGV distinguishes itself from the terminal tractors through its automated and unmanned operations. It uses various sensors and positioning systems to properly navigate itself. The design of the AGV is therefore solely functioning as a loading surface to accommodate containers (Johansson, 2023; Ross, 2023).

With regards to vertical stacking and lifting, there are several approaches to the choice of vehicle. One of them is the reachstacker. This vehicle is equipped with a driver's cab situated beneath a hydraulic lifting arm that enables the lifting and stacking of containers. Although the reachstacker is capable of moving containers horizontally, its primary function is stacking. The reachstacker is a large vehicle, and due to this size, it requires adequate space for manoeuvring and moving, resulting in requirements of having certain widths in the aisles between the container stacks. This vehicle has the capability to stack approximately three containers in depth, and five to six containers in height (Argelius, 2023; Johansson, 2023). A similar vehicle for vertical stacking is the top handler. These are similar to reachstackers as it possesses the same features, but have a design more similar to a classic forklift. Top handlers are mainly used for lifting and stacking containers but are also capable of transporting them inside the terminal. However, the major difference between top handlers and reachstackers is that top handlers can only move the containers vertically, meaning that they can only stack containers in one row. Reachstakers on the other hand can reach above container rows allowing them to stack containers over several rows (Ross, 2023; Hinz, 2011)

An alternative among vertical stacking is the use of cranes which have several areas of use. One especially important use case in a container terminal is the cranes used by the quay, the ship-to-shore (STS) cranes. The STS cranes are an essential piece of equipment that efficiently transfers containers between the ship and the shore. These cranes are typically large and powerful, as they need to have the ability to reach across the width of the largest container ships. The STS usually operates on rail tracks along the quay, allowing for flexibility of positioning. Some container terminals even employ mobile cranes which are even more flexible. STS cranes discharge containers from the vessel down to either the apron or onto a designated vehicle for horizontal transportation. (Wiese, 2012, 7-12; Johansson, 2023; Paijmans & van Boxelaere, 2023)

Other types of cranes typically used in container terminals for vertical movements are the ones appointed solely for stacking within the storage yard. These include rubber tyred gantry cranes (RTG) and rail mounted gantry cranes (RMG). Gantry cranes move over container stacks, allowing for a high density of stacking as containers can be placed in high piles and close to each other (Paijmans & van Boxelaere, 2023; Ross, 2023). The forward and backward travel over the stack is achieved through either the movement on rails or on rubber tires. The difference between the two types of gantry cranes is that RMG is restricted to a certain stack of containers as it operates on rails, thus reducing its flexibility to be used wherever container stacking is needed. Conversely, the RTG's tires allow it to move between different container aisles, enabling more operational flexibility. Both these gantry cranes are connected to horizontal transportation through the use of designated lift up and drop off points (Wiese, 2012, 13-17).

Lastly, many container terminals use empty container handlers for vertical stacking. These are designed as top handlers but have the restricted capacity of solely lifting empty containers, thus most commonly used in terminals where there is a high flow of empty containers needed to be handled. They are lighter and cost less than ordinary container handling vehicles, making them more suitable than wasting conventional more powerful container handling vehicles for these types of operations (Löthner, 2023)

Beyond vehicles procured for horizontal or vertical transportation, some vehicles are acquired for filling the purpose of both. These vehicles can be referred to as hybrids where the most common vehicles are shuttle carriers and straddle carriers. These vehicles are equipped with a mechanism that allows them to lift and move containers both horizontally and vertically, making these vehicles very versatile. The design of straddle and shuttle carriers are very similar, but with the difference that shuttle carriers are smaller and they can only carry one container at a time and stack two high. The bigger size of a straddle carrier means that it can carry more containers simultaneously and stack containers higher, up to four high. (Kalmar, n.d.:a; Johansson, 2023). Due to these two vehicles' horizontal and vertical capabilities, shuttle carriers and especially straddle carriers can be responsible for the entire process from the point where a container is discharged by an STS crane until the container leaves the container terminal with an external mode of traffic. However, to enable stacking, it is required that containers are positioned so that the straddle and shuttle carriers can traverse over them. This means that it is a necessity to leave sufficient space between adjacent rows of containers to accommodate the wheels of the vehicles. Additionally, this restricts the maximum height to which containers can be stacked. (Ross, 2023; Johansson, 2023)

4.1.1.4 Building the container handling fleet

The reasons behind a certain combination of container terminal vehicles vary based on each container terminal’s specific conditions and operations. The available space is an important aspect to consider, both in terms of available area and in terms of the number of containers handled yearly. A high number of handled containers combined with a limited area to operate on forces container terminals to become more space efficient and find new ways of stacking containers more densely in their storage yards. Improved stacking capabilities can be achieved by considering various combinations of vehicles making up the fleet, as different vehicles have various stacking abilities and require different amount of space to operate on. Regarding vertical stacking vehicles, gantry cranes are most effective, followed by straddle carriers and reachstackers, and lastly, shuttle carriers, top handlers and empty container handlers, see *table 4.1* (Löthner, 2023; Ross, 2023; Johansson, 2023). Putting this into approximate numbers, the RTG can stack 1000 TEUs per hectare, straddle carrier 750 TEUs per hectare, and reachstacker 500 TEUs per hectare (Kalmar, n.d.:b). Increased stacking density requires more planning to keep track of the locations of containers and limits the flexibility as containers may be stuck in the inner parts of the stack (Paijmans & van Boxelaere, 2023).

The need for stacking density must be put in relation to the financial perspective of container terminals. Different solutions of stacking are associated with different costs of investment, labour costs, and operating costs. As the capabilities of stacking improve, the cost of investment increases (Kalmar, n.d.:b). Small to medium or terminal start-ups therefore tend to be better suited for the use of reachstackers. These terminals handle smaller volumes of cargo and require vehicles that are less expensive. Conversely, large terminals tend to use RTG and RMG systems for stacking as it results in increased stacking efficiency. These types of vehicles require a bigger investment, but for larger container terminals handling higher volumes of containers and generating higher annual revenue, this bigger investment would have a shorter payback time (Ross, 2023; Johansson, 2023). If space is not a scarce resource, straddle carriers can be a suitable alternative (Paijmans & van Boxelaere, 2023). One of the main reasons for choosing a hybrid vehicle such as straddle carriers relates to the fact that it solely requires the procurement of one type of vehicle. Straddle carriers can be responsible for the complete container journey, compared to using vertical stacking vehicles needing to incorporate additional vehicles for horizontal transportation. Every handover between a vertical stacking vehicle and a vehicle for horizontal transportation is a time-consuming activity where there is a risk of losing track of specific containers (Ross, 2023).

Moreover, the rate of automation of the container terminal has an impact on the choice of fleet. Most vehicles used in container terminals today have an automated substitute. However, the most common vehicles to be automated today are STS and gantry cranes. The automation of these vehicles is a fairly simple process and once automated, these cranes have the ability to stack containers more efficiently than their manual counterparts (Johansson, 2023; Ross, 2023). Regarding vertical stacking, straddle carriers and shuttle carriers are more commonly automated than reach stackers, top handlers and empty container handlers. For horizontal transportation, an automated approach would correspond to the use of AGVs. However, terminal tractors are also becoming more automated but the manual version is still dominant in today’s operations, see *table 4.1* (Löthner, 2023; Johansson, 2023).

Additionally, the combination of vehicles might be based on the container terminal's historical fleet. A complete fleet transformation would require major financial resources, meaning that container terminals may choose to follow the system that was previously implemented rather than purchasing a completely new fleet. This can be the case despite the fleet not being perfectly adapted to the current operations and preferences (Paijmans & van Boxelaere, 2023).

Nowadays, numerous container terminals operate non-stop, which means their fleet of vehicles doesn't have any scheduled pauses for fuelling or recharging. Consequently, for all the vehicles requiring a refill at the same time, an extra vehicle is necessary to continue the operations, leading to the need for a larger overall fleet (Paijmans & van Boxelaere, 2023; Ross, 2023; Johansson, 2023).

4.1.1.5 Fuel

Currently, most of the vehicles used in container terminals are powered by diesel. However, STS cranes and certain yard cranes are usually electrified, and the use of diesel can therefore be relegated to those vehicles that are not tied to one single location. The fixed location of these cranes makes it easier to provide constant power as a stationary charging solution can be installed (Paijmans & van Boxelaere, 2023; Ross, 2023). The diesel-driven vehicles have, however, lately been influenced by the alternative fuel of hydrotreated vegetable oil (HVO). HVO is a renewable diesel produced from various vegetable oils and fats (ETIP Bioenergy, 2020, 1). This fuel has been adopted in several container terminals due to its reduced emissions compared to diesel when considering a life cycle perspective and as it is compatible to use in regular diesel engines. Worth highlighting, is that the reduction of emissions takes place during the manufacturing process. Hence, the reduced environmental effects resulting from using this fuel do not occur locally as the emissions from the vehicles remain the same. Instead, the positive impact is observed on a global level (Ross, 2023; Löthner, 2023). Research and real-life examples from ports have proven HVO to have the potential of reducing greenhouse gas emissions by up to 80 percent when considering a life cycle perspective (Argelius, 2023; Niemi *et.al.*, 2016, 2).

Additionally, depending on the container terminal's geographical location, the price and accessibility of HVO varies (Paijmans & van Boxelaere, 2023; Magnusson, 2023; Argelius, 2023). This process of refuelling can occur in several ways. Either a truck refuels the vehicles while being parked, or the terminal can be equipped with underground tanks and its own gas station. (Argelius, 2023; Ross, 2023; Paijmans & van Boxelaere, 2023).

Despite the positive impact of HVO and it being a good step towards more sustainable operations, there is still a need for more initiatives having less effects on the environment. Electrification of container terminal operations is an increasingly emerging trend where several vehicles within container terminals are currently being substituted with corresponding electrical versions (Ross, 2023). All vehicles presented earlier are available in electric versions to some extent, however, the use of these electric versions is variously established in the container terminal operations. Electric RTGs and RMGs are frequently used by container terminals today. However, these are often stationary meaning they get access to electricity through attached cables. Electric versions of terminal tractors are considered to be one of the most established non-stationary EVs, as it is a fairly simple machine to electrify and there is a high demand for these electrified terminal tractors. Electric reachstackers and AGVs are also being offered and used today, but not to the same extent as the electric terminal tractor. The remaining vehicles can also be obtained in electric versions but are not widely used in container terminal operations today, see *table 4.1* (Löthner, 2023; Johansson, 2023). These electric versions of currently used vehicles are mostly charged with a plug-in solution that powers the vehicle while stationed. The charging occurs between shifts and during breaks, or during the hours when the container terminal is not operating (Johansson, 2023; Argelius, 2023; Paijmans & van Boxelaere, 2023). Still, electrical vehicles represent a minority of a complete fleet due to higher procurement costs and additional investments in necessary power grid infrastructure. To completely transition to an electric fleet, container terminals will need to upgrade their power supply subscriptions and grid infrastructure since their current operations are not heavily reliant on electricity (Argelius, 2023; Stemmler, 2023; Ross, 2023).

Table 4.1: Summary of features for the different vehicles used in container terminal operations

Vehicle	Horizontal/ Vertical	Stacking efficiency	Automation rate	Electrification rate
Automated Guided Vehicle	Horizontal	–	High	Medium
Empty Container Handler	Hybrid	Low	Low	Low
Reachstacker	Hybrid	Medium	Low	Medium
Rail-Mounted Gantry Crane	Vertical	High	High	High
Rubber-Tired Gantry Crane	Vertical	High	High	High
Shuttle Carrier	Hybrid	Low	Medium	Low
Straddle Carrier	Hybrid	Medium	Medium	Low
Terminal Tractor	Horizontal	–	Medium	High
Top Handler	Hybrid	Low	Low	Low

4.1.1.6 Infrastructure

Ensuring a consistent and reliable supply of electricity is an important aspect for the daily operations of container terminals as these types of closed-looped transportation systems are in general heavy consumers of electricity (Stemmler, 2023; Ross, 2023). The infrastructure of power grids is at different stages of development depending on the country, thus access to sufficient power capacity can vary. An electrification of container terminal operations will require increased consumption of electricity and a bigger subscription of power supply as a majority of the fleet today is driven by diesel. Additionally, there appears to be little to no internal electricity production happening in ports today. This since the power provided by the local power grid is often cheap and easily accessible, creating no incentives to have their own electricity production. (Argelius, 2023; Ross, 2023; Paijmans & van Boxelaere, 2023).

Another important part of the infrastructure of container terminals is the construction and design of the road network. These are formed to optimise the movement of vehicles and to improve productivity. One location especially exposed to heavy traffic is the roads placed beneath the STS cranes. This is where containers are discharged from the vessels and loaded for horizontal transportation. Similarly, there are spots exposed for heavy traffic at the designated pick up and drop off points by the container stacks in the storage yards (Argelius, 2023; Ross, 2023). The roads in container terminals are designed to carry significant weight to avoid wear of roads. Special types of asphalt or concrete are being used to minimise the formation of tracks, resulting in less sway for tall vehicles carrying heaving goods. The road material has various properties, affecting the maintenance of the road and the possibility to make instalments on top or in the road. Further, some ports suffer from insufficient documentation of underground pipes and cables contributing to difficulties in construction work (Kalman, 2023).

4.1.1.7 Performance measurements

Container terminals measure their performance based on several key performance indicators. One performance measurement present in all container ports today is the profitability of the business. Another measurement is the number of containers handled per year as this is directly correlated to the generated revenue of the business. Other measurements are more focused on productivity. These include containers stacked per hectare, number of containers moved per hour by vehicle or person, turnaround time of ships, turnaround time of external trucks entering the facility and utilisation of vehicles (Argelius, 2023; Paijmans & van Boxelaere, 2023; Stemmler, 2023; Ross, 2023). These measurements are important as container terminals are highly dependent on productivity to face the increasing demand for global maritime trade. Therefore, it is fundamental to continuously strive towards improving these key performance indicators (World Bank, 2007, 41-42).

4.1.2 Political: Managing and governing of ports

4.1.2.1 Different port administration models

There are several different port administration models existing today, distinguished by a variety of characteristics. The characteristics include whether the port's provision of services is governed by a public port authority or a private player, whether the port has a local or global orientation, the ownership of the port land and infrastructure, the ownership of superstructure and equipment in the port, and the status of port labour. Based on these characteristics, four main categories of port administration models can be identified. These are the public service port, the tool port, the landlord port and the private service port (World Bank, 2007, 81-84).

The public service port has an overall public character. The public port authority is in charge of all the necessary services required for the port to function properly, including the ownership, maintenance, and operation of all available assets, both fixed and mobile. While this fully public ownership allows for a unity of command that increases decision-making efficiency, it also means that investments are made with taxpayers' money, making them a stakeholder that must be considered. Involving more stakeholders decreases decision-making efficiency. Additionally, these ports are usually experiencing underinvestment due to government interference and their dependency on the government budget (World Bank, 2007, 81-84; Ross, 2023). While some ports, such as the port of Helsingborg, continue to adopt this administration model, the overall number of ports utilising it is decreasing (Argelius, 2023). Several ports that were previously public service ports are now in the process of transitioning towards a landlord port structure (World Bank, 2007, 81-84).

The landlord port model is distinguished by its mix of public and private involvement. In this model, the public port authority acts as both a regulatory body and a landlord, with private companies responsible for port operations. Private operators lease infrastructure from the public port authority by paying a yearly fixed sum per square metre. Private operators are responsible for maintaining their own buildings and acquiring their own container handling equipment. Additionally, they are able to make their own investments in infrastructure on terminal grounds as needed for their operations (World Bank, 2007, 81-84). The efficiency in investment decisions can differ significantly among various private terminal operators. Local players who manage only one terminal require the involvement of fewer stakeholders when making investment decisions. On the contrary, players belonging to a larger global organisation must navigate through more bureaucracy as decisions must be suitable not only for a single terminal but for all their terminals (Ross, 2023). The port of Gothenburg and the port of Antwerp are two examples of ports adopting the landlord port model (Magnusson, 2023; Paijmans & van Boxelaere, 2023).

In the tool port model, the port infrastructure and the superstructure, including container handling equipment, are owned, developed, operated and maintained by the public port authority. Management of contracts with ship owners and container handling on board vessels and on the quay is on the other hand controlled by private companies. Decisions regarding investments in port infrastructure and equipment are therefore only made by the public sector, allowing for an unity of command in investment decisions but the involvement of numerous stakeholders and a risk for underinvestment due to government interference and dependency on the government budget. The split of operational responsibilities between private and public players in this model is considered to be a major problem, as it risks impeding operational efficiency within the port. However, this model is advantageous to use as a means of transition to a landlord port model. It can function as a transition catalyst in cases where confidence in private players is not yet established and when trying to minimise time spent on establishing legal statutes to privatise former state assets (World Bank, 2007, 81-84).

The private service ports are fully privatised and are today few in numbers but can be found in the United Kingdom. Port of London, Port of Southampton and the Forth ports are three of the biggest container ports in the United Kingdom all being privately owned (Baird et al., 2006, 70). In these types of ports, the land is privately owned, which sets it apart from other port management models. This requires a transfer of ownership of the land from the public to the private sector and in some cases also the regulatory responsibilities. In the United Kingdom for instance, privatised ports are mostly self-regulating due to the lack of port regulators. This allows for maximum flexibility and efficiency with respect to port operations and investment decisions. However, the risk with this type of arrangement is that the port land may be sold or repurposed for non-maritime activities, thereby making it difficult to reclaim for its maritime use (World Bank, 2007, 81-84).

Reviewing these different administration models, it becomes apparent that reforms and investment decisions are made at different levels of the port's organisational structure and with different degrees of unified command. This affects the complexity of decision making as a various number of stakeholders need to be involved. Investment processes become more efficient and less complex when investment decisions are made at the local level with fewer stakeholders involved (Ross, 2023). Financial power for investments also differs depending on the adapted administration model. For models where ports are publicly owned, i.e. the public service port, the tool port and the landlord port, there are different country-specific regulations regarding profit reinvestments which affect the port's financial power. In Denmark for instance, regulations require Danish ports to reinvest all generated profit into their own port operations, restricting these ports from doing investments in external public projects. This results in larger budgets for investment in comparison to ports in countries without such regulations (Sjöstrand, 2023).

4.1.2.2 Pressure from closeby communities and stakeholders

Many big cities originate from the establishment of a port. For instance, the port of Antwerp was founded relatively near the current location of the city centre of Antwerp (Paijmans & van Boxelaere, 2023). However, as ship sizes increased and the demand for deeper drafts and longer berths grew, ports gradually shifted their operations away from the city centres. The rapid mechanisation and specialisation of port operations also contributed to this shift, accompanied by an increased operational scale and scope. This resulted in a higher demand for storage space, making ports increasingly space intensive. At the same time, rapid expansion of housing in cities has put pressure on ports to become more space efficient (World Bank, 2007, 76). These ports' air, noise and light pollution also have a major impact on surrounding residential areas. As a result, ports such as the port of Helsingborg and the port of Bergen have experienced heavy pressure from local governments and nearby cities to relocate their operations to new locations further away from the city centres. Therefore, the current locations of these ports are limiting their willingness to undertake significant long-term projects and investments (Argelius, 2023; Kringstad, 2023).

4.1.3 Economic: Revenue streams and cost drivers in container ports

The total number of containers handled by countries in the European Union (EU) was 77 million in 2012. By 2021, this number had increased to 98 million, implying an annual growth rate of 2.7 percent (Eurostat, 2022). This continuous growth indicates an economic growth and increased demand for maritime shipping and thus for container terminal operations.

There are several different revenue streams produced by the operations within a container terminal. Arriving ships are charged with port dues along with several different service fees such as towing and piloting. Once containers are discharged from vessels, administrative fees and fees for on-land services can be collected, such as handling and storage of containers. Depending on the port’s administration model, these revenue streams will be allocated to different players within the port. Rental of land, infrastructure, and superstructure is another type of revenue stream, but this is only available to owners within certain administrative models. For instance, the public owners of a landlord port gain substantial revenue from rental fees from the private companies operating within the port (World Bank, 2007, 259; Magnusson, 2023). Considering these revenue streams is an important aspect in investment situations, not only for the port itself to ensure the feasibility and economic sustainability of an investment, but also for potential lenders wanting to ensure there is sufficient financial security. Estimating future revenue streams is a complex process since it requires evaluating various factors such as projected traffic levels, the anticipated overall economic growth of the country, possible currency exchange rate risks, interest rates, the future political situation, and other related factors (World Bank, 2007, 98). Along with these various revenue streams come certain expenses. These can be categorised into three main types of costs, cost of fuel to run the vehicle fleet, cost of staff and capital expenditure to maintain infrastructure and superstructure within the port (Paijmans & van Boxelaere, 2023; Stemmler, 2023; Argelius, 2023). The distribution of these costs is dependent on the type of fuel used to power the vehicles in the fleet. Having electric-driven operations instead of diesel-driven would have an impact on the distribution between these three major expenses, reducing fuel costs while capital expenditures would increase (Paijmans & van Boxelaere, 2023).

4.1.4 Environmental: The environmental impact of port operations

Today, the global maritime industry is responsible for approximately 3 percent of the global greenhouse gas emissions, whereas ports contribute to this share (Alamoush, 2022). The environmental impact from ports is not only caused by its operations and its vehicles but also by external traffic arriving at the ports. This includes emissions from ships calling at the quay and emissions from external vehicles arriving to pick up containers for further freight transport (Braathen, 2011, 31).

In addition to CO_2 emission, port operations also result in emissions of toxic air pollutants. *The European Sea Ports Organisation* (ESPO) classifies this as the top environmental concern of the sector (Puig *et al.,* 2021, 16). These air pollutants come from the use of different vehicles for horizontal transportation and vertical stacking, as these are heavily reliant on the use of fossil fuels. Further, there are sources of air pollution linked to the refineries, oil and gas storage facilities and power generators within ports. These harmful air pollutants consist of oxides of nitrogen, oxides of sulphur, carbon monoxide, carbon dioxide, volatile organic compounds and particulate matter such as dust. Environmentally, these emissions contribute to increased global warming, acidification and ozone layer depletion. Socially, these air pollutants have a negative impact on the health of the staff and closeby populations as they can cause cardiovascular and respiratory diseases among other things (Alamoush, 2021, 16-18; EPA, 2022a; Naturvårdsverket, n.d., 12).

Noise and light pollution are also apparent in ports, caused by the various cargo handling vehicles within the port. This negative environmental impact has grown to become a frequently discussed subject as it affects nearby residents and wildlife (Ross, 2023; Paijmans & van Boxelaere, 2023). Noise pollution includes problems related to disturbance, stress related illnesses, hearing loss, blood pressure and general losses of productivity (Puig *et al.,* 2021, 17; EPA, 2022b). However, the largest source of noise emission is not originating from the port operations itself, but from the arriving vessels. The noise from ships comes from the auxiliary units needed to provide the ship with energy while stationed in the port. Today, ships are shifting towards becoming gradually more electrified, thus becoming less of a source of air pollution. To support this shift, the port's power grids need to be able to supply vessels with this increased use of electricity (Naturvårdsverket, n.d., 24-25; Alamoush, 2021, 18).

Ports take various measures to mitigate their environmental impact. In a report made by ESPO in 2021, results showed that 86 percent of the studied ports had set up an environmental monitoring programme. It also highlighted that a large share of ports today uses environmental policies and objectives to achieve environmental improvements (Puig *et al.,* 2021, 5-6). These objectives are often linked with having continuous growth and remaining profitable. To achieve the environmental aspects of these objectives, ports are implementing performance measurements, such as energy efficiency and CO_2 emission per moved container. Additionally, it has become an important factor for terminals to demonstrate and highlight their sustainability work to the public. Therefore, many ports currently put a effort into publishing sustainability reports as a way of communicating their efforts to improve their climate impact (Argelius, 2023; Paijmans & van Boxelaere, 2023; Magnusson, 2023; Stemmler, 2023).

Port operations are connected to several of the SDGs formed by the UNs. By improving ports' carbon footprint and reducing their emitted pollutants, several of the SDGs can be addressed. The fact that ports are linked to several different SDGs highlights ports' importance in achieving the 2030 sustainable objectives. It also emphasises the pressure that exists on ports to make their operations sustainable (Alamoush, 2021, 28-29).

4.1.5 Legal: Policies and regulations in port operations

It is commonly believed that the primary objective of the laws of a port is to establish a framework for the development and management of ports. Nevertheless, it is also important to highlight that a legal framework for ports must also facilitate the port's ability to compete effectively in both domestic and international transportation markets (World Bank, 2007, 131-150).

Today, each country has its own unique legal and institutional context, making the exact purpose of a national port law different from one country to another. This means that national laws and regulations are dependent on unique local circumstances, making it difficult to make in-depth descriptions of regulations as these cannot be generally applicable to every port. It is therefore only possible to give general descriptions of the legal situation in a port based on overarching regulatory issues and to get a deeper insight one must analyse each country separately. Issues needing to be addressed in all regulatory frameworks for ports include safety within the port, environmental restrictions, loading and discharging of goods, conduction of vessels and crisis management (World Bank, 2007, 131-150).

However, there are cross-national policies and initiatives in place affecting ports. *The Trans-European Transport Network* (TEN-T) is one example of a cross-border policy addressing the establishment of a comprehensive transportation network across Europe. This network comprises all types of transportation, from maritime shipping routes and ports to railway lines and roads. The objective with this policy of EU-level is to close gaps between member countries and to strengthen their economic, territorial and social cohesion. The TEN-T policy supports the adoption of innovation, novel technologies and digital solutions in all transportation modes. The objective is to improve infrastructure utilisation, minimise the environmental impact of transportation, increase energy efficiency, and enhance safety levels. The biggest ports in Europe are all included in TEN-T and these ports must comply with certain regulations but also have access to special grants (Sjöstrand, 2023; European Commission, n.d.).

On a national level, pro-environmental regulatory incentives and pressures on local organisations are becoming more occurring around the world. For instance, in Sweden, *Klimatklivet* is one of the country's biggest climate initiatives which has issued investment aids of 5.5 billion SEK between 2015 to 2020. The purpose of this initiative is to financially support regional and local organisations, such as ports, in their efforts to invest in fossil-free technology to reduce their emissions of greenhouse gases (Sjöstrand, 2023; Pädam, 2020, 19-23). Another example of this is the formation of local regulations by the *California Air Resource Board* (CARB) to tackle the issue of poor air quality in California, USA. CARB has put pressure on the ports within the state to reduce their air pollution by requiring all diesel-driven cargo handling equipment within the ports to be phased out by 2030 (Ross, 2023).

4.1.6 Social: Social equity in port operations

Labour is a crucial asset in port operations due to the labour-intensive nature of the industry. Having a sufficiently educated and satisfied port workforce is a key success factor for ports to be able to ensure operational efficiency and to remain competitive in today's international trade environment. Managing port labour is an act of balancing required to consider employees' social equity, port owners' and operators' commercial needs to stay competitive, and the interaction between the port's and government's interests. Social equity for port labour encompasses interests such as reasonable incomes, social security, education and training, workplace influence and workplace safety (World Bank, 2007, 318-326). In port operations, the latter aspect holds particular significance due to the use of large vehicles for handling heavy goods, posing a considerable risk for accidents (Argelius, 2023). Improving within these areas of social equity would lead to increased labour motivation and higher productivity (World Bank, 2007, 318-326). Considering the social equity impacts of an electrification of port vehicles, for example, it would have both commercial and social impacts. From a commercial standpoint, it would have effects on investments, operational costs and other commercial aspects. From a social perspective, the port labour force would likely respond positively to this transition, as it would lead to a reduction in air pollutants, as well as decreased vibrations and noise (Ross, 2023).

4.1.7 Applying the PESOEL framework on container terminals

Based on the current situation of the container terminal industry, a PESOEL analysis was conducted. This analysis summarises and highlights the most important and influential trends and perspectives within the industry today, see *table 4.2.*

Table 4.2: The PESOEL framework applied on container terminals

Political	There are four distinct administration models in container terminals that vary in terms of complexity in the investment decision-making process due to these models having: - Variations in number of stakeholders involved - Investment decisions are made at various levels of the organisation - Variations in financial power Ports are experiencing pressure from local governments and nearby cities to relocate operations - Current locations of these ports are limiting their willingness to undertake significant long-term projects and investments
Economic	There are several revenue streams being allocated to various players within the container terminal based on the port's administration model: - Port dues along with different connected service fees from vessels - On-land service fees for container handling and storage - Rental fees for the use of land, infrastructure and superstructure for owners Estimating future revenue streams is a decisive process for investment decisions and the possibility to receive loans There are three main cost drivers in the operations of container terminals: - Cost of fuel to operate the vehicle fleet - Labour costs - Capital expenditure to maintain infrastructure and superstructure An electrification of port operations reduces fuel costs and increases capital expenditures

Social	Port operations is a labour-intensive industry, emphasising the importance of having well-developed labour management. This is to ensure sufficient social equity for employees and to stay competitive in today's international trade environment Safety is an extra important aspect within container handling due to the use of large vehicles for handling heavy goods, posing a considerable risk for accidents Port labour force would likely respond positively to an electrification of current operations, as it would lead to a reduction in air pollution, as well as decreased vibrations and noise
Operational	There are several different vehicles used in container terminals, mainly powered by diesel. The combination of vehicles in a fleet depends on: - Whether the vehicles are capable of transporting containers horizontally, vertically or both - Vehicles' need for manoeuvring space - Vehicles' stacking ability - The price of vehicles - Vehicles' possibility to be operated automatically - The historical combination of vehicles used in the container terminal The different vehicles are currently at different stages of electrification As the number of handled containers increases, space becomes an increasingly important asset for terminals. This affects the rate at which container terminals need to improve their space efficiency Some container terminals have round-the-clock operations which increases the demand for higher utilisation of vehicles To facilitate productivity, vehicles follow predetermined driving patterns with main routes and designated container pick-up and drop-off points Ports are heavy users of electricity already, relying on the local power grid to supply them with sufficient power. An electrification will possibly result in the need of upgrades of current power supply subscriptions

Environmental	Ports are heavy emitters of: - CO_2, resulting in global warming - Air pollution, having negative effects on the health of the society - Noise and light pollution, resulting in problems related to disturbance and stress related illnesses Ports take various measures to mitigate their environmental impact, such as: - Setting up environmental monitoring programmes - Setting up environmental policies and objectives - Forming environmental key performance indicators - Publishing sustainability reports to communicate their efforts of becoming more environmentally friendly Ports are linked to several SDGs which highlights port operation's importance in achieving the global 2030 sustainable objectives. It also emphasises the pressure that exists on ports today to improve and make their operations more sustainable
Legal	Today, each country has its own unique legal and institutional context, making the exact purpose of a national port law different from one country to another Cross-national projects and initiatives exist, putting both pressures through policies and allowing for sustainable investments by providing subsidies

4.2 A current overview of conductive road-attached ERS

An implementation of a conductive road-attached ERS in a closed-looped transportation system is part of a bigger electric transformation. An electrification does not only include an implementation of ERS but also the deployment of sufficient power supply infrastructure and an introduction of EVs if no earlier initiatives to electrify have been taken (Natanaelsson *et.al.*, 2021, 9-10). These three main areas of an ERS implementation along with other aspects important to consider, will be covered in this section. Lastly, the key takeaways from this section will be presented in a SWOT analysis framework, where the ERS technology and its comparative advantages and disadvantages over competing solutions will be presented, see *table 4.3*.

4.2.1 Implementation of a conductive road-attached ERS

Implementing an ERS has several subsequent effects impacting both diesel-driven and static charging closed-looped transportation systems. This type of charging infrastructure can make EVs a more viable option compared to substitutes driven by fossil fuels. In theory, ERS can provide EVs with an infinite range, never having to stop for charging, allowing for less range anxiety for EVs (Kloo *et al.,* 2019, 21; Elonroad, n.d.:a; Torstensson, 2023). By having the option to charge more frequently while driving, the required battery capacity in EVs can be drastically reduced. This allows car manufacturers to be able to install smaller sizes of batteries in EVs, resulting in environmental and economic benefits as material usage and production costs can be reduced. The smaller battery sizes also allow for more space to be available in each car and reduce the weight of EVs resulting in less electric power being used (Torstensson, 2023; Alaküla, 2023).

A conductive on-road ERS rail can either be attached on top of the road or be milled into the road. These two alternatives have various advantages and disadvantages. The material properties of the surface of the road have an impact on which of the two options that is most favourable. Hard road materials such as concrete can be difficult to mill into, constituting a potential challenge for the in-road rail (Palmqvist, 2023). In addition, the location of gas pipes, power lines and other infrastructure below ground is often insufficiently documented, causing potential problems when milling the ERS into the road (Kalman, 2023).

The choice between on-road or in-road ERS has different effects on safety. A rail placed on top of the road creates a more uneven road surface compared to the in-road option, which is not desirable for roads where heavy and tall vehicles are operating, as this can cause heavy sways (Kalman, 2023). Additionally, the ERS placed on top of the road has compatibility issues with certain vehicles, such as two-wheeled vehicles where the risk for accidents would dramatically increase with an on-road ERS (Natanaelsson *et al.*, 2021, 64; Pettersson *et al.*, 2017, 37). Whether the ERS is glued on top or milled into the road, there will be a need for additional maintenance. The ERS placed on top of the road has proven to have some difficulties to be held in place when many vehicles are crossing the rail (Kalman, 2023). Snow and ice removal is another issue needing to be addressed, as conductive charging requires the pick-up and the rail to be in contact at all times for the vehicle to be charged. There are special snow ploughs designed for the on-road ERS, while the in-road ERS does not require any special snow removal techniques (Torstensson, 2023; Palmqvist, 2023). Rails can also be heated up internally, freeing the rail from snow and ice but also causing the road to become more slippery as the melted water settles and freezes in tracks on the road (Palo *et al.*, 2020, 18; Palmqvist, 2023). Maintenance of the road beneath the rail also needs to be considered. The axle loads of vehicles in closed-looped transportation systems are in general higher compared to vehicles on public roads. This results in faster road wear and the creation of wheel tracks which in turn makes these heavier vehicles sway more. Thus, roads in closed-loop transportation systems need to be replaced more frequently compared to public roads (Kalman, 2023). The ERS's ability to be compatible with these frequent replacements of roads is important to consider when comparing the on-road and in-road ERS. A rail placed on top of the road can be more easily removed when replacements of roads need to be done, in comparison to the in-road option (Palmqvist, 2023). However, there are techniques today for replacing roads which only require the worn parts of the road to be replaced, making both options as viable (Kalman, 2023).

Implementing an ERS in a closed-looped transportation system has several safety risks connected to it. The rails have different frictional properties compared to the road material which can cause longer breaking distances and a risk for skidding. However, in closed-looped transportation systems vehicles do not usually reach speeds where differences in frictions of the road would have an impact (Natanaelsson *et al.*, 2021, 64; Pettersson *et al.*, 2017, 37; Kalman, 2023). However, the perceived risk of having a rail with different frictional properties in the middle road can cause changes in driving behaviour (Natanaelsson *et al.*, 2021, 64; Pettersson *et al.*, 2017, 37). Additionally, having a power supply unit on ground level comes with certain safety risks of people coming in contact with the rail. However, today's ERS technologies are only powered when vehicles are on top of the rail, thus making the current apparent risk of being run over the main issue in this situation. The power of the rail is switched off at lower speeds to prevent people from accidentally coming in contact with the rail when vehicles are stationary or moving slowly (Pettersson *et al*., 2017, 37; Kloo *et al.,* 2019, 18; Palmqvist, 2023).

Certain conductive ERS solutions today have the ability to collect data from the rail. The use of this data has several beneficial use cases. It can enable the detection of vehicles travelling above the rail. This allows for the ERS to only supply power on stretches of the rail where cars are located, thus addressing the safety concerns of having electricity on a ground level. It also enables the development of a billing system making it possible to collect revenue from electricity consumption and usage of the charging system (Torstensson, 2023). Vibration data can be collected, measuring weights and allowing for the detection of traffic accidents further along the road. Temperature and humidity data is also possible to collect, allowing for the detection of slippage on upcoming stretches of the road (Palmqvist, 2023).

4.2.2 Electrification of vehicle fleet

In order for EVs to be able to be charged by an ERS, a pick-up need to be attached beneath the EV. This pick-up is in direct contact with the rail, supplying power to both drive the vehicle's motion and to charge the vehicle's batteries. This pick-up can be modified to be compatible with most of the different types of EVs operating in closed-looped transportation systems, ranging in size and shape (Löthner, 2023; Johansson, 2023).

Once an EV is sufficiently equipped, an ERS implementation can reap the benefits of transitioning from a diesel-driven fleet to a fleet driven by electricity. From an environmental perspective, fossil fuel dependency can be heavily reduced by switching to an electricity-driven fleet, resulting in lower CO_2 emission (Shulte *et al.*, 2018, 2; Lindgren, 2020, 10). An EV transition would also reduce emissions of respiratory harmful air pollutants, such as nitrogen oxide (NOx), even when only a minor part of the fleet is electrified (Pettersson *et al.*, 2017, 32). However, considering a life cycle perspective, it is also important to take into account the production of batteries and how the used electricity has been produced. The production of electricity can determine if an electricity-driven fleet actually is more environmentally friendly than a corresponding diesel-driven alternative. Research suggests that coal-based marginal electricity used in an ERS is causing more emissions than having a fleet driven by diesel, whilst using renewable means of producing electricity has a significantly lower climate impact (Shulte *et al.*, 2018, 9). The production of batteries constitutes environmental risks, mainly being linked to the use of fossil fuels in the production and the mining and processing of heavy metals that are used in the batteries (Shulte *et al.*, 2018, 6; Natanaelsson *et al.*, 2021, 13). Additionally, with no sufficient recycling, the supply of raw materials for these EV batteries will become a production bottleneck in the near future as demand for EVs rapidly increases. In this case, having smaller batteries when using an ERS compared to static charging, will gain both environmental and economic future benefits (Alaküla, 2023).

Diesel-driven heavy vehicles today contribute to high levels of noise pollution. At speeds above 50 kilometres per hour, the noise from tires is dominant but at lower speeds, the diesel engine is the primary source of noise pollution. Speeds are generally lower in closed-looped transportation systems, thus more noise pollution comes from the diesel engine which can be reduced by EV's quieter engines (Pettersson *et al.*, 2017, 12 & 65). Socially, this lower noise pollution and less vibrations caused by the EVs often improves the working environment for employees (Kloo *et al.,* 2019, 20).

4.2.3 Ensuring sufficient power supply

Introduction of a sufficient power supply infrastructure is necessary for an ERS to be implemented. The electric road needs to be connected to a power station every 1-1.5 kilometres. Each power station has a transformer, isolating and switching down the voltage from the main grid. These power stations will occupy additional space in closed-looped transportation systems (Pettersson *et al.*, 2017, 34; Natanaelsson *et.al*., 2021, 63; Torstensson). However, when compared with current diesel-driven refuelling infrastructure, the difference in required space is marginal. On the other hand, compared with static charging, the use of charging stations increases the need for additional space drastically (Argelius, 2023; Paijmans & van Boxelaere, 2023). Charging stations also constitute obstacles that potentially can be runned into, increasing safety risks for drivers (Alaküla, 2023).

A sufficient and reliable grid capacity is a prerequisite for the ERS to be able to be operational at all times (Natanaelsson *et.al*., 2021, 70; Alaküla, 2023). The reliability of power systems can today vary between different countries, affecting the potential of an ERS (Ayaburi *et al.,* 2020, 2). Presently, in competitive power systems, each market participant is responsible for their own investments in generation capacity. Consequently, during peak demand these power systems may become undesirably unreliable which can have harmful impacts on electricity-demanding closed-looped transportation systems. By subscribing to anticipated demand for capacity during peak conditions, each individual consumer's power supply is limited to their subscribed capacity, which increases the reliability of the surrounding power system (Doorman, 2005, 1-2). When implementing ERS in closed-looped transportation systems, it is important to have a high enough power supply subscription for the ERS to be operational at all times. It is therefore important to consider if the closed-looped transportation system's current power supply subscription is enough to supply the ERS with power. However, power supply subscriptions are expensive, thus there is an economic motivation in trying to keep power supply levels in subscriptions down (Alaküla, 2023). If the current operations within a closed-looped transportation system are fully driven by diesel, then this subscription would need to be drastically upgraded if an ERS were to be implemented. Having a partly or completely electrified system on the other hand, would possibly require no additional expansions to current subscriptions (Alaküla, 2023). Typically, the number of vehicles requiring power from the road simultaneously and the charging capacity of each vehicle are the primary factors driving the ERS power demand. However, ERS can distribute its charging more throughout the day compared to conventional static charging. Thanks to this more continuous power supply, peak demand can be drastically reduced and thus expensive subscription upgrades can be avoided (Torstensson, 2023; Alaküla, 2023).

4.2.4 Investments and cost savings

The hardware investment costs for an ERS are currently uncertain as companies developing this charging solution have not reached large enough production volumes and sales to gain sufficient large-scale advantages. Therefore, established price models for a large-scale implementation of ERS do not currently exist (Torstensson, 2023). What is certain however, is that the investment cost of implementing an ERS in a diesel-driven closed-looped transportation system will increase for each additional kilometre of road and vehicle that is electrified (Pettersson *et al.*, 2017, 38). The coverage of roads needed to be electrified with ERS to fully meet the charging needs of EVs can be simplified as the ratio between the EV's electricity consumption on a fixed stretch of road and the power the rail can provide on this same route. Therefore, having an ERS capable of providing higher power, allows for less coverage of ERS on the roads and thus less hardware investment cost. However, higher ERS power is more expensive, resulting in a trade-off between the investment cost for higher power capacity and the investment cost for more ERS hardware. Having a bigger closed-looped transportation system will require more kilometres of road to be electrified to reach sufficient coverage to fully meet the charging needs of the system’s EVs. The optimal placement of an ERS is on the roads with the highest intensity of traffic, as this allows for the greatest vehicle exposure, maximising the number of charging hours from the ERS (Alaküla, 2023; Torstensson, 2023).

ERS is currently a more hardware-demanding charging solution compared to a static charging infrastructure. Additional investment costs need to be spent on supporting equipment, such as the pick-up attached beneath the vehicle, in order for the EV to be operable in an ERS. The ERS rail needs to cover a substantial stretch of the total road net whereas static charging requires several charging stations. However, ERS’s ability to distribute the charging more throughout the day without EVs having to stop for charging, allows for battery sizes to be reduced. It also results in fewer required vehicles to be operational simultaneously as higher rates of vehicle utilisation can be achieved by being able to charge the vehicles while in motion compared to a static charging solution. Therefore, the investment cost for total battery capacity can be significantly reduced as fewer vehicles are required, with each vehicle needing less battery capacity (Alaküla, 2023).

Whether a closed-looped transportation system is being electrified using an ERS or a conventional static charging infrastructure, there will be a need for additional investments in a more robust power supply infrastructure. ERS specifically, requires investments in power stations which will vary in price based on the power the rail is expected to provide. The power supply subscription will possibly need to be upgraded to support the increased usage of electricity. As earlier mentioned, this subscription can be kept to lower levels for ERS than static charging infrastructure, thus possibly a lower investment cost in subscription upgrades (Alaküla, 2023; Torstensson, 2023).

Once an ERS is up and running, there are several economic benefits of electrifying a closed-looped transportation system with an ERS. In both the US and in Europe, prices of electricity are lower compared to alternative fuels, such as diesel. Operating a fleet on electricity instead of diesel will therefore save money. These cost savings will be increasingly significant as the number of electrified vehicles in the fleet increase and as the hours' vehicles are operating per day increase. However, prices of fuel vary between countries which affects the overall cost savings from the choice of fuel (Natanaelsson *et.al*., 2021, 12; GlobalPetrolPrices, 2023; GlobalPetrolPrices, 2022). Further, the ERS capability of achieving higher utilisation allows for increased efficiency of the current fleet and a possibility to generate the same revenue from a smaller number of vehicles. It also opens for more available space as charging stations can be avoided. More available space results in a greater capacity of the closed-looped transportation system, thus a possibility to expand current operations and generate higher revenue (Alaküla, 2023; Torstensson, 2023). However, there are some additional costs that come with implementing an ERS. The pick-up is worn when being in direct contact with the rail, thus needing recurring replacements. Special techniques for snow removal will also be required. However, on roads with intensive traffic, i.e. the roads most optimal for an ERS deployment, snow and ice do not settle to the same extent, resulting in less need for maintenance (Alaküla, 2023). There are also costs for maintenance of the EVs, but in comparison to a diesel-driven vehicle, these costs are in general less (Löthner, 2023). Lastly, there will be a deprecation cost, increasing depending on the size of the investment in ERS hardware and infrastructure. These investments can be depreciated over the total number of hours vehicles use the ERS, thus making depreciation an hourly cost (Torstensson, 2023).

4.2.5 Standards and regulations

With a limited number of permanent ERS installations today, there are not any internationally preferred ERS-technology and no standards in place (Natanaelsson *et.al*., 2021, 19). Standardisation is a multi-faceted process that can occur at various technology levels, from an overall level, focusing on the complete design of the ERS, down to component-level. Different stakeholders may have divergent views on this standardisation process. Countries with high levels of transit traffic are in greater need of a standard for ERS, especially those that import or export significant volumes of goods via international waterways. The automotive industry seeks the appointment of a champion technology to enable efficient production of large vehicle series, with the parties owning or manufacturing various ERS all vying for their system to be selected as the champion. There is also a divergence of opinions between those desiring ERS for urban transport and those desiring such systems for transporting goods (Pettersson *et al.*, 2017, 44-45). For a closed-looped transportation system, the necessity for standards for ERS can be questioned. These systems are separated from the public, thus the need for interoperability with surrounding systems is reduced (Akaküla, 2023; Bateman *et al.*, 2018, 17). Even though there are no standards in place, there are existing national laws applicable as regulatory requirements in the construction of an ERS. This includes requirements on evenness, visibility, road marking adaptations, friction and electricity safety (Pettersson *et al.*, 2017, 44-45). Further, an ERS implementation is also subjective to various regional, national and EU-level subsidies and regulations within several areas, such as air pollution and labour safety (Sjöstrand, 2023; Paijmans & van Boxelaere, 2023).

4.2.6 Applying SWOT analysis framework on an implementation of ERS

To summarise the effects and conditions of implementing a conductive road-attached ERS in a closed-looped transportation system, a SWOT analysis was conducted. The SWOT analysis was divided up into two scenarios based on if the current transportation system's fleet was driven by diesel or electricity using static charging. Several strengths, weaknesses, opportunities and threats are common between the two scenarios and some are different, see *table 4.3.*

Table 4.3: The SWOT analysis framework applied to an implementation of ERS in two different scenarios

	Compared to current diesel-driven fleet	**Compared to current static charging electric fleet**
STRENTHS	100% utilisation of fleet vehicles Environmental advantages - Less CO_2 emission - Less air pollutants - Less noise pollution Social advantages in improving the workplace for employees by using EVs Lower prices for electricity than diesel Lower maintenance costs for EVs than diesel-driven vehicles	100% utilisation of fleet vehicles Less range anxiety for EVs Reduced battery capacity required - Smaller battery sizes - Reduced material usage in production - More available space in EVs - Smaller investment cost for total battery capacity Less number of required EVs in the fleet Smaller power supply subscription for ERS ERS occupies less space compared to charging stations - Fewer obstacles risking being crashed into

WEAKNESSES	Weaknesses of the on-road rail alternative - It causes an uneven road surface - Not compatible with certain vehicles - Proved to have difficulties staying in place Limitation in supply of materials for battery production in near future Big investment cost - Hardware - Electrification of vehicles - Power supply subscription Additional operative costs - Depreciation - Regular replacements of pick-up - Snow and ice removals	Weaknesses of the on-road rail alternative - It causes an uneven road surface - Not compatible with certain vehicles - Proved to have difficulties to stay in place Bigger investment cost for hardware Additional maintenance costs - Regular replacements of pick-up - Snow and ice removals
OPPORTUNITIES	Data gathering can provide additional features - Foreseeing accidents further down the road - Detection of upcoming slippery road surfaces - Charging only turned on beneath the car Compatible to a majority of vehicles operating in closed-looped transportation systems Potential subsidies covering parts of the investment	Data gathering can provide additional features - Foreseeing accidents further down the road - Detection of upcoming slippery road surfaces - Charging only turned on beneath the car Compatible to a majority of vehicles operating in closed-looped transportation systems Potential subsidies covering parts of the investment

THREATS	Safety risk of having electricity on ground level Risk of changed driver behaviour Heavy road wear in closed-looped transportations system, thus a need frequent maintenance of underlying road Risk of having to use electricity produced from fossil fuels Unreliable surrounding power grid Risk of not becoming the future standardised ERS to be used	Safety risk of having electricity on ground level Risk of changed driver behaviour Heavy road wear in closed-looped transportations system, thus a need frequent maintenance of underlying road Risk of not becoming the future standardised ERS to be used

5 Analysing an implementation of a conductive road-attached ERS in a container terminal

The information presented in chapter 4 along with the theoretical foundation provided in chapter 3 are analysed in this chapter. Firstly, additional delimitations and assumptions, necessary for subsequent stages of the work process, are defined. Thereafter, based on the findings, three overarching areas of consideration when implementing an ERS in a container terminal are presented.

5.1 Delimitations from the current overview

Upon creating a current overview of ERS and container terminals, it became apparent that additional delimitations needed to be added. Firstly, the discussion was delimited to solely focus on the implementation of an ERS rail milled into the road. The decision between the two rail options did not appear to be decisive in terms of the difficulty of maintaining the road, rather other aspects proved the in-road rail to be more desirable. The on-road rail would cause additional sway for large vehicles handling heavy cargo, thus become an increasing safety issue. Moreover, the on-road rail proved to have some issues staying in place. The current overview also highlighted that fleets used in container terminals today are powered by diesel. Hence, the following discussion was based on the assumption that the fleet is fully diesel-driven and thus the vehicles in the fleet will have to be substituted with electric counterparts. The scenario of switching from a static charging electric fleet to a fleet powered by ERS was therefore excluded. Lastly, it was assumed that enough ERS will be implemented in to allow for the entire electrical fleet to be powered by an ERS. Meaning that no additional static charging supplements will be needed in this assumption.

5.2 Operational considerations when implementing an ERS

The optimal locations to install an ERS rail have proven to be the locations with the highest ADT, as the ERS rail can be utilised by the maximal number of vehicles. Container terminals do generally have standardised road networks consisting of main highways with higher intensity of traffic. These are usually located by the quay, thus it being the optimal location for the ERS rail to be installed. There are also designated locations for loading and discharging of containers by the quay and in the storage yard where vehicles tend to spend a substantial share of their operating time waiting. These pick-up points and the roads leading up to these locations are also relevant for an ERS to be installed.

The various vehicles in a container terminal have proven to have different capabilities, advantages and disadvantages. These vehicles are variously compatible with using an ERS charging solution. The initial consideration for vehicle compatibility with an ERS is how easily and cost-effectively a pick-up can be attached. Elonroad has previously implemented solutions to fit regular buses and vans, having a regular wheelbase and sufficient space to attach a pick-up on the underside (EvolutionRoad, n.d.; Torstensson, 2023). Therefore, container terminal vehicles possessing similar attributes to a regular bus or van are considered most compatible with regards to attaching a pick-up, i.e. terminal tractors, reachstackers, AGVs, top handlers and empty container handlers. Nonetheless, it has been proven that a pick-up can be attached to any vehicle, but with varying levels of difficulty. Another consideration for vehicle compatibility with an ERS is the level of progress that different vehicles have made towards electrification. The vehicles having reached the furthest in their electrification are more likely to use an ERS as these are more established and widely used in container terminals today. Many stationary vehicles used in container terminals, such as RTGs and RMGs, are already predominantly powered by electricity. However, these vehicles are typically connected to a power source through cables and thus will not require an ERS for charging. As a result, RTGs and RMGs do not need to be considered in an ERS implementation. Out of the various types of vehicles used in container terminals, terminal tractors, reachstackers, and AGVs, have made the most progress in terms of electrification. Lastly, the vehicle's different driving patterns need to be considered as this emphasises each vehicle's opportunity to utilise the ERS rail placed on the most heavily trafficked roads. Terminal tractors, shuttle carriers, straddle carriers, and AGVs are the vehicles that spend the most time on heavily trafficked highways, which means that they are the ones that would benefit the most from an ERS placed on these locations. Assuming that the fleet of a container terminal has already been optimised to meet its specific operational needs and is not influenced by its past fleet, then electrifying the current vehicles would simply involve replacing the current diesel-powered vehicles with their electric counterparts. Given this assumption and the three aspects of compatibility, the ideal vehicles for a container terminal today would be terminal tractors and AGVs, followed by reach stackers, top handlers and empty container handlers, shuttle carriers and straddle carriers. It is important to note that RMGs and RTGs do not require ERS implementation and can be excluded from consideration.

The data collecting abilities of an ERS can be utilised in container terminal operations to measure and improve the productivity of container terminals as well as to boost safety. The data collection can enable more accurate measurement of current key performance indicators and facilitate the development of additional, more specified new ones. Data collection can also enable terminal operations to become more digitised, thereby opening opportunities for increased automation and efficiency.

One of ERS's unique attributes is its ability to provide higher uptimes for vehicles operating within the container terminal, as time spent on refuelling or recharging can be eliminated. Implementing an ERS will therefore either increase container handling capacity as more vehicles can be operative simultaneously or retain container handling capacity with the use of fewer vehicles. This is particularly relevant to container terminals that operate round-the-clock, as these are in need to improve vehicle utilisation and as these vehicles have no appropriate time to refuel or recharge.

Space has proven to be an increasingly valuable resource in container terminals. The current availability of land affects the rate at which container terminals need to improve their space efficiency to face the increased demand for container shipping and handling. ERS is a considerably space efficient charging solution compared to static battery charging. However, compared to current ways of refuelling vehicles in container terminals, the differences are small. Current operations use refuelling trucks and diesel reserves installed below ground, resulting in an ERS not necessarily contributing to space effectiveness.

5.3 Sustainability considerations when implementing an ERS

5.3.1 Economic sustainability

Container terminal’s three main expenses are the cost of fuel, the cost of staff and capital expenditures. Implementing an ERS has proven to generally reduce the cost of fuel as the prices of electricity are lower than the prices of diesel. Worth highlighting, the prices of electricity and diesel vary depending on the country in which the container terminal is operating. Further, implementing an ERS will result in higher capital expenditures as there will be additional investment costs for the ERS hardware, the transition to EVs and having to upgrade current power supply subscriptions.

Currently, there are no established price models for a large-scale implementation of ERS and therefore, the hardware investment cost for an ERS is uncertain. However, it has been shown that there is a certain share of occupancy of roads that needs to be covered by rail for an electric fleet to fully and solely utilise an ERS. Assuming that this share of coverage would be the same for all sizes of container terminals, we can conclude that a container terminal with a bigger operating area will need more hardware, thus a bigger hardware investment cost to achieve full electrification with an ERS. When comparing the hardware investment cost for different container terminals, the area can be put in relation to the number of containers handled each year to achieve comparable results and to understand how significant ERS investment will be for each container terminal. The number of handled containers is a reliable metric to explain the size of a container terminal's operations, which in turn is linked to the container terminal's revenue and financial power.

Currently, EVs are in general more expensive than diesel-driven counterparts. Moreover, since most container terminals currently rely on diesel-powered fleets, container terminals will need to replace major parts of their fleet with EVs, resulting in a substantial investment cost. The bigger the fleet is, the bigger the EV transition investment will be. However, the total number of vehicles will be able to be reduced as an ERS solution allows for fewer buffer vehicles due to continuous charging. Additionally, maintenance costs are generally lower for EVs than for diesel-driven vehicles. When comparing the EV transition investment for different container terminals, the number of vehicles that need to be electrified can be put in relation to the number of containers handled each year. This is to, once again, achieve comparable results and to understand how significant an investment will be for each container terminal.

Container terminals have proven to be heavy consumers of electricity as certain operations, such as discharging containers from vessels using STS cranes, are already powered by electricity. However, transitioning to an EV fleet will significantly increase the demand for electricity and lead to higher peaks in power consumption. As a result, it will be necessary for container terminals to invest in upgrading their current power supply subscriptions. Worth highlighting, the quality of the power grid can vary between countries, affecting the possibility of making these necessary upgrades. When comparing the necessary power supply subscription upgrades for different terminals, it is important to consider the current subscription in relation to the future subscription required for a fully electrified fleet. This approach ensures comparable results and provides insight into how big of a transition an electrification will be for each terminal.

Numerous programs worldwide offer subsidies to ports and container terminals that are transitioning to more sustainable operations. Implementing an ERS contributes to less environmental impact for container terminal operations, making such subsidies applicable to the ERS technology. These financial aids can be of great benefit when having to address the increased capital expenditures of implementing an ERS. However, these subsidies can often vary widely in terms of availability between countries, predetermined requirements, subsidised amounts, and other factors.

5.3.2 Environmental sustainability

It has been proven that ports are currently major emitters and that they are under significant pressure from local communities and regulatory bodies to address this issue. Consequently, there has been a growing emphasis on ports and container terminals to become more environmentally friendly and reduce their climate impact. An implementation of ERS and a transition to EVs has shown promising results in reducing the emissions of CO_2, air pollutants and noise pollution. As a result, terminals with greater pressure from stakeholders and a stronger focus on environmental issues are more likely to be motivated to implement an ERS. However, it is important to adopt a broader perspective to accurately assess the extent of the environmental benefits of ERS. It is essential to ensure that the electricity used by EVs in the container terminal is produced in an environmentally friendly way and that all hardware, including EV batteries, is evaluated from a life cycle perspective. Further, HVO has proven to become an increasingly popular fuel to replace diesel due to its lower climate impact, reaching reductions of greenhouse gas emissions by up to 80 percent, and the fact that it can be used in the same combustion engines that previously used diesel. This alternate fuel is risking to minimise the environmental advantages of transitioning to an electricity powered fleet. However, it is worth noting that on top of certain supply issues and higher prices compared to diesel, the lower climate footprint of HVO is not achieved in its combustion process, but rather in its underlying production process, resulting in local emissions in container terminals remaining the same.

5.3.3 Social sustainability

Ports and container terminals are dangerous workplaces. Implementing an ERS would constitute additional potential safety risks. One significant safety concern in container terminals’ labour-intensive operations is the presence of high voltage electricity at ground level. However, this issue is currently being addressed by ERS developing firms, which means it is not expected to be a persistent safety risk in the future. The risk of slippage in container terminals located in cold climates can also be a potential problem for ERS, as melted snow and ice freeze in wheel tracks, making the road extra slippery for the heavy vehicles operating within the container terminal. On the other hand, the workforce has been shown to encourage the implementation of sustainable solutions that can enhance their work environment. By substituting diesel-powered vehicles with EVs, staff at container terminals will experience reduced noise pollution and less vehicle vibrations, which may be an incentive great enough for staff to encourage this transition.

5.4 Stakeholder considerations when implementing an ERS

The four administration models that exist in ports today, have proven to affect the complexity and efficiency of investment decision making. Firms involved in ERS development require a steady stream of funds to remain operational. Therefore, they may favour ports with efficient decision making and swift investment processes as this allows for a faster determination of whether additional revenue can be generated. Therefore, some administration models are considered preferable for ERS developing companies than others. The most desired port administration model is the private service port model as this involves the least number of stakeholders and allows for more direct and swift decision making. The landlord port model with local players managing only one or a few terminals is the second most favoured option. This is due to the involvement of few stakeholders and investment decision making being made at a more local level compared to the land port model with players belonging to a larger global organisation. Like the private service port model, this model is considered privatised. However, container terminals adopting this model still answer to an additional stakeholder, the owner of the port. Tied in third place are the tool port model and the public service port model as these are owned by a public entity which facilitates the decision making through the unity of command. On the other hand, publicly owned ports are hampered by multiple stakeholders, which creates additional complexity, and they are subject to government budget constraints. Lastly, the least desirable administration model is the landlord port model having port operators belonging to a larger global organisation. These terminals need to involve numerous stakeholders and must navigate through a lot of bureaucracy as decisions must be suitable not only for a single terminal but for all their terminals. However, if an ERS can be sold and successfully implemented in one of these terminals, this administration model has the potential to generate additional sales for the ERS developer across all the operator's terminals worldwide.

It is currently recognised that each country has its own distinct legal and institutional context, making the exact purpose of a national port law different from one country to another. Consequently, ports are subject to different laws, regulations and timeframes, making them varyingly pressured to improve their operations to become more sustainable. Ports that face the highest pressure must accelerate their sustainability efforts the most to achieve their sustainability goals. This necessitates and motivates quicker decisions-making processes for environmentally friendly investments, such as an implementation of an ERS. An example of a port under pressure is the Port of Long Beach, which is currently facing stringent deadlines from the CARB to reduce their operational emissions. To meet these requirements, the port has now started to investigate different types of environmentally friendly solutions. One of the solutions being explored is an ERS offered by Elonroad, which has the potential to significantly decrease the port's emissions through a full electrification (Ross, 2023). The Port of Long Beach and ports in similar situations are therefore seen as more relevant for an ERS as they have greater incentives to make prompt investment decisions to meet the appointed sustainability targets.

Ports experience varying pressures from local stakeholders to relocate their operations to allow for an expansion of nearby city infrastructure and to reduce local air, noise and light pollution. This limits the port's willingness to undertake significant long-term projects and major investments. Consequently, an ERS implementation might not be as pertinent for such ports as they might soon be compelled to relocate their operations.

6 ERS compatibility framework for container terminals

Using the analysis performed in chapter 5, a framework was created in this chapter which included all aspects worth considering when assessing the suitability of a container terminal to adopt an ERS. This framework was the foundation for creating a tool used for assessing and comparing the compatibility of an ERS in various container terminals.

6.1 Factors and parameters included in the framework

A framework was created to emphasise and highlight the most essential aspects to consider when identifying which container terminal is the most relevant for an ERS implementation. The framework consists of 13 parameters corresponding to the areas needed to be covered. These parameters were categorised into four overarching factors based on common characteristics to create a clear division between the included parameters. The container terminal's compatibility of implementing an ERS can be rated by studying these parameters. A summary of all factors and parameters that are included in the framework is presented in *figure 6.1*. The relevance of each parameter is explained below, along with suggested approaches for measuring each parameter.

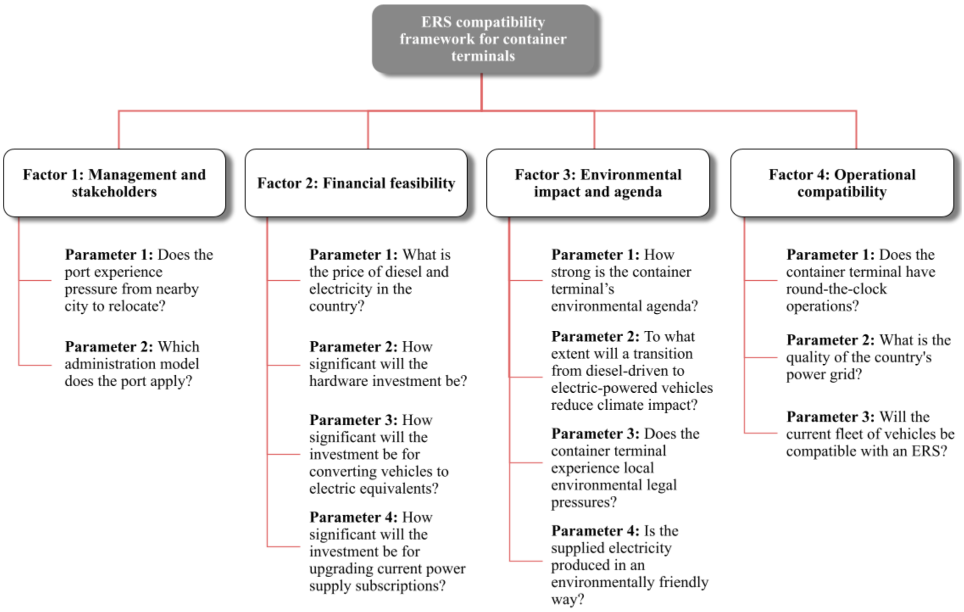


Figure 6.1: The ERS compatibility framework for container terminals

6.1.1 Factor 1: Management and stakeholders

There are two distinct parameters associated with the management and stakeholders factor that differ among container terminals, *see figure 6.1*. The first parameter refers to the fact that certain ports experience pressure from nearby cities to relocate their operations to allow the expansion of city infrastructure and to reduce local emissions affecting the closeby city. Argelius (2023) in the Port of Helsingborg highlighted the relevance for this parameter, as this port experienced heavy pressure to relocate their operations. Ports experiencing this scenario are less willing to make long-term investments, e.g. an investment in an ERS, as their operations are risking being relocated in the near future. Therefore, ports not experiencing the pressure to relocate are more likely to carry out an investment in an ERS, thus more favourable. This parameter will result in a binary answer of either a “Yes” or a “No” depending on whether they are under pressure or not. Additionally, this information is not necessarily public information which may require the user of the model to contact the container terminal to obtain this data.

The second parameter corresponds to the type of administration model used in the port. Different models include varying numbers of stakeholders, unity of command, and levels of bureaucracy, resulting in various degrees of investment decision efficiency. For an ERS developing firm, quick decisions are desirable as it corresponds to shorter lead times and possibly faster generation of revenue. The different administration models are therefore ranked based on their assessed investment decision efficiency as presented in *section 5.4*:

1. The private service port
2. The landlord port with local operators
3. The public service port & the tool port
4. The landlord port with global operators

The value assigned to each container terminal for this parameter depends on the rank of their adopted administration model. Information regarding each port's administration model is mostly publicly available.

6.1.2 Factor 2: Financial feasibility

The financial feasibility factor includes four underlying parameters varying between different container terminals, see *figure 6.1*. Firstly, investigating the varying prices for diesel and electricity in each country will provide insights into how significant the cost savings for fuel will be by switching to an electric powered fleet. There are currently public databases providing data on country-specific prices for diesel and electricity (GlobalPetrolPrices, 2023; GlobalPetrolPrices, 2022). This parameter can be measured by putting the diesel price in relation to the electricity price in the country of which the container terminal is operating within. As long as the same currency is used for both the diesel price and the electricity price, the specific currency in which the prices are measured do not affect the calculation of the relationship between the two variables.

The remaining three parameters are intended to provide comparable insights into how significant the investments will be for a full-scale implementation of an ERS in a diesel-driven container terminal. Different significance of the investment results in different willingness to proceed with a full-scale ERS implementation. The parameters refer to investment costs for hardware, for an EV transition and for upgrading current power supply subscriptions. For the hardware investment, the amount of hardware required is in direct correlation to the total area within the container terminal. The area will in turn be put in relation to the number of containers handled yearly, as this is a reliable metric for explaining the size of the container terminal's operations and its financial power. For the EV transition investment, the number of diesel-driven vehicles in the container terminal emphasises the number of vehicles needing to be replaced by an electric counterpart, thus how significant the EV investment will be. This parameter will also be put in relation to the number of containers handled yearly in the container terminal. The final parameter, upgrades of power supply subscription, will measure the relation between the current power supply subscription and future power supply subscription once an ERS implementation has been carried out. This parameter shows the significance of a power supply subscription investment, but it also provides an indication of what will be required from the container terminal's power supply infrastructure and its local power grid. The number of containers handled yearly can often be accessed publicly. However, container terminal-specific data, such as the operating area, number of diesel-driven vehicles and current power supply subscriptions, is most often not publicly available data.

A value for the future power supply subscription is particularly complicated to produce, as it requires making projections and estimations of the future. It can be estimated with several different methods with various levels of complexity based on the predetermined time frame and desired accuracy of the results. In this case, the future power supply subscription will be addressed with relatively simplified assumptions and estimations, prioritising time efficiency at the expense of reduced accuracy. The estimation will be based on the sum of the current power supply subscription and the additional power required to charge all vehicles when shifting from diesel-powered vehicles to electric counterparts. This additional power will be estimated based on the number of vehicles converted to electric substitutes, the required power supply of the rail and the share of time each vehicle needs to be on the rail to be sufficiently charged, see *formula 1* below.

$$Additional\,power = \#\,Electrified\,vehicles \cdot Power\,by\,rail \cdot \%\,Time\,on\,rail \quad (1)$$

6.1.3 Factor 3: Environmental impact and agenda

The environmental impact and agenda factor includes four underlying parameters varying between different container terminals, see *figure 6.1*. Firstly, investigating the environmental agenda of each container terminal provides insights into each container terminal's motivation to become more environmentally friendly, thus their willingness to invest in green technology, such as an ERS. Aspects to look at to reach a conclusion on this parameter will be based on publicly available data:

- Is there a published sustainability report?
- Quality of sustainability report?
- Is their environmental vision and mission clearly promoted?
- How ambitious is their environmental vision and mission?
- Are all the major emission areas addressed?

A reasoning approach will be adopted, based on these aspects, to classify this parameter into high, medium or low environmental agenda for each container terminal.

The second parameter to consider within this factor is the environmental impact of transitioning from a diesel-driven fleet to a fleet consisting of EVs. It has been proven that the more diesel-driven vehicles that are able to be electrified, the bigger the reduction of environmental impact will be. Therefore, this parameter will investigate the current number of diesel-driven vehicles that have a potential to be electrified in a fleet. However, HVO has proven to be a popular fuel to use in container terminals which can reduce greenhouse gas emissions by 80 percent. For example, Argelius (2023) mentioned that the Port of Helsingborg has converted their entire fleet to operate on HVO instead of non-renewable diesel. Thus, an electrification of these vehicles will only result in a 20 percent greenhouse gas emission reduction compared to the diesel-driven vehicles. Summarising the number of diesel-driven vehicles and the number of HVO-driven vehicles in the fleet, bearing in mind that HVO emits 20 percent greenhouse gases compared to diesel, provides a measure of the environmental impact of implementing an ERS and transitioning to an EV fleet. The number of diesel-driven and HVO-driven vehicles in a container terminal is not necessarily public information which may require the user of the model to contact the container terminal to obtain this data.

Thirdly, local environmental legal pressures are also a parameter to consider in this factor. Container terminals are experiencing heavy legal pressures to reduce their emissions, making them investigate how they could electrify their operations. Ross (2023) in the Port of Long Beach emphasised the relevance for this parameter, as this port is currently under increased legal pressure to make its operations more sustainable. This type of pressure impacts each container terminal's willingness to invest in green technology, such as an ERS. Information regarding this tends to be publicly available. A reasoning approach will be adopted, comparing the local legal pressure for the different container terminals to classify this parameter into high, medium or low legal pressure.

The final parameter within this factor is whether the electricity is produced in an environmentally friendly way or not. Using electricity produced from fossil fuels in an EV fleet has proven to not result in any major reductions of climate impact if transitioning from a diesel-driven to a fleet powered by electricity. This parameter is important to be able to ensure that an implementation of an ERS and a transition to an EV fleet will have positive environmental effects. There are currently public databases providing information on the share of electricity production from renewables, such as hydropower, wind, geothermal, and solar power, in each country (Our World in Data, 2022). This information will be used to ensure that the electrification of container terminal operations achieves the intended reduction of environmental impact.

6.1.4 Factor 4: Operational compatibility

The operational compatibility factor includes three underlying parameters varying between different container terminals, see *figure 6.1*. The first parameter investigates whether the container terminals have round-the-clock operations or not. This will provide insights into whether an ERS's ability to improve vehicle uptime is actually beneficial. The parameter will result in a binary answer of either a "Yes" or a "No". Access to this information is restricted and cannot be obtained from publicly available sources. Therefore, the user of the model must contact the container terminal to request this data.

The second parameter to be taken into account is the quality of the power grid in the country where the container terminal operates. An ERS implementation will not be possible if there is not a sufficient power grid to support the electrified operations. This parameter will be measured by putting the country's electricity production capacity in relation to the country's population. This allows for production capacities that are not influenced by the size of the country. There are currently public databases providing information about both populations and energy production capacities in each country (EIA, 2021; World Population Review, 2023).

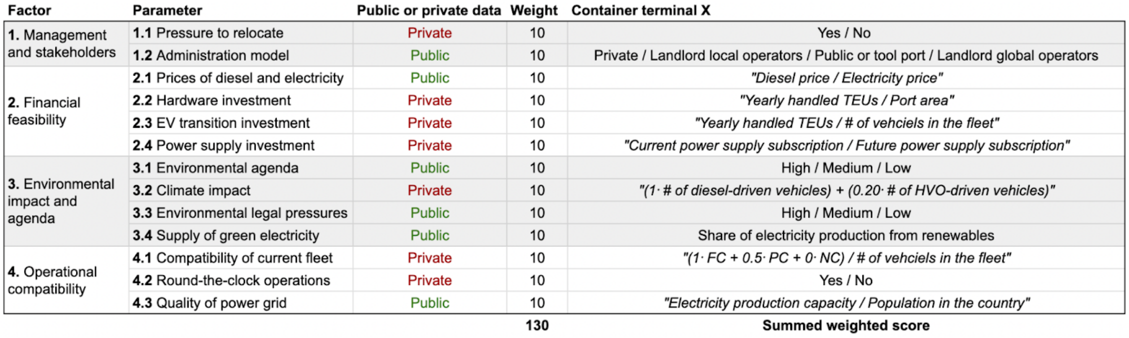
The last parameter within this factor is aimed at examining whether the container terminal's fleet is compatible with an implementation of ERS or not. Assuming that the fleet of a container terminal has already been optimised to meet its specific operational needs and is not influenced by its past fleet, then electrifying the current vehicles would solely involve replacing the current diesel-powered vehicles with electric counterparts. Given this assumption, this parameter will provide an insight into which container terminals that currently have the most optimal fleet to utilise an ERS. As presented in *section 5.2*, a threefold division of vehicles based on compatibility was formed. These can be listed as fully compatible vehicles (FCV), partially compatible vehicles (PCV) and not compatible vehicles (NCV). The following vehicles are included in the three different divisions:

- FCV: Terminal tractors & AGVs
- PCV: Reach stackers, top handlers, empty container handlers, shuttle carriers & straddle carriers
- NCV: RMGs & RTGs

To assess the fleet, the number of vehicles in each category is summarised and each of the three categories of compatibility is weighted differently. The differently weighted categories are then summed up and put in relation to the total number of vehicles in the container terminal. This results in a calculated value that provides a comparable insight into which container terminal's fleet that is the most compatible with an ERS without being influenced by the size of the fleet. The set-up of the fleet is not necessarily public information which may require the user of the model to contact the container terminal to obtain this data.

6.2 Applying the framework by using a developed tool

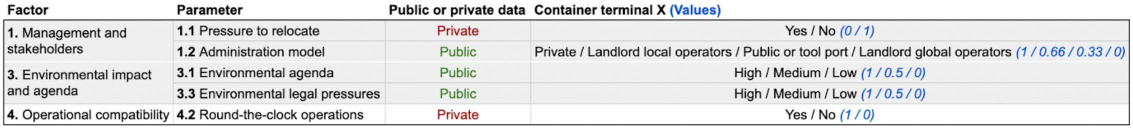
The framework and its parameters illustrated in *figure 6.1* was the foundation for creating a tool used for assessing and comparing the compatibility of an ERS in various container terminals. *Figure 6.2* illustrates the tool and shows how each parameter was measured or calculated on the basis of the presented approaches in *section 6.1*. Using this tool will provide insights into which container terminal that will be the most suitable for an ERS implementation. These insights can be used to specify marketing efforts, to lay the groundwork for sales material and to gain an understanding of a container terminal's compatibility to using an ERS.



Factor	Parameter	Public or private data	Weight	Container terminal X
1. Management and stakeholders	**1.1** Pressure to relocate	Private	10	Yes / No
	1.2 Administration model	Public	10	Private / Landlord local operators / Public or tool port / Landlord global operators
2. Financial feasibility	**2.1** Prices of diesel and electricity	Public	10	*"Diesel price / Electricity price"*
	2.2 Hardware investment	Private	10	*"Yearly handled TEUs / Port area"*
	2.3 EV transition investment	Private	10	*"Yearly handled TEUs / # of vehciels in the fleet"*
	2.4 Power supply investment	Private	10	*"Current power supply subscription / Future power supply subscription"*
3. Environmental impact and agenda	**3.1** Environmental agenda	Public	10	High / Medium / Low
	3.2 Climate impact	Private	10	*"(1· # of diesel-driven vehicles) + (0.20· # of HVO-driven vehicles)"*
	3.3 Environmental legal pressures	Public	10	High / Medium / Low
	3.4 Supply of green electricity	Public	10	Share of electricity production from renewables
4. Operational compatibility	**4.1** Compatibility of current fleet	Private	10	*"(1· FC + 0.5· PC + 0· NC) / # of vehciels in the fleet"*
	4.2 Round-the-clock operations	Private	10	Yes / No
	4.3 Quality of power grid	Public	10	*"Electricity production capacity / Population in the country"*
			130	**Summed weighted score**

Figure 6.2: The tool for assessing and comparing the compatibility of an ERS implementation in various container terminals. Italicised parameter input in quotation marks indicate calculations, while the remaining parameter inputs correspond to fixed response options.

In the tool, all factors and the underlying parameters from the framework are included as they are all intended to be examined. A column has been added to address the availability of the data needed to be collected for each parameter. This is either stated as "Public" or "Private", depending on if the information is easily accessible via public sources or if the data needs to be collected by reaching out to each considered container terminal. This provides the tool with versatility, as the users themselves can choose the scope of the evaluation. If there is an urgency to reach a result, the parameters requiring private data can be excluded as these in general will be more time-consuming to obtain. Additionally, a column for weighting the different parameters has been added, since each user of the tool is characterised by an unique situation and thus have various preferences for which of the 13 included parameters they consider most important. Therefore, the user of the tool will be able to allocate 130 available shares freely across all parameters based on the considered relative importance of each parameter. The allocation of these shares can be carried out in many different ways. Different amounts of effort and time can be put into it depending on desired accuracy of the weighting. It can be done in both larger discussion groups or more individually. Further, the value for each parameter comes in various formats, with some consisting of a number of predetermined response options and others being more quantitative. Ultimately, all parameter values will be quantified and transformed to a value between 0 and 1 to obtain comparability between all included container terminals and to enable a total score to be calculated. The parameters consisting of a few predetermined response options will be converted into quantitative equivalents on a linear distribution between 0 and 1 depending on the number of response options, see *figure 6.3*. Some of the quantitative values will reach numbers outside the range between 0 and 1. These values are transformed by putting the highest measured value of the parameter in relation to the value in question, making all values fall in the range between 0 and 1, with the highest measured value in the parameter being 1. The value for each parameter will be weighed and summed to obtain an overall weighted score. The container terminal with the highest total score is the terminal considered most attractive for an ERS implementation according to this tool.



Factor	Parameter	Public or private data	Container terminal X (Values)
1. Management and stakeholders	**1.1** Pressure to relocate	Private	Yes / No *(0 / 1)*
	1.2 Administration model	Public	Private / Landlord local operators / Public or tool port / Landlord global operators *(1 / 0.66 / 0.33 / 0)*
3. Environmental impact and agenda	**3.1** Environmental agenda	Public	High / Medium / Low *(1 / 0.5 / 0)*
	3.3 Environmental legal pressures	Public	High / Medium / Low *(1 / 0.5 / 0)*
4. Operational compatibility	**4.2** Round-the-clock operations	Private	Yes / No *(1 / 0)*

Figure 6.3: The parameters converted into quantitative equivalents on a linear distribution between 0 and 1

Worth highlighting is that some of the generated values will not be in absolute terms, meaning that they might not represent reality. Instead, they are in relation to the different considered container terminals. For instance, if a container terminal is assigned the value "High" for parameter *3.1 Environmental agenda*, it may not necessarily be considered high when compared to all container terminals worldwide. However, it can be concluded as ”High” when compared to the specific set of container terminals considered in this evaluation. Being able to consider only a fixed number of container terminals in this way makes it easier and more time efficient to assign values to each container terminal.

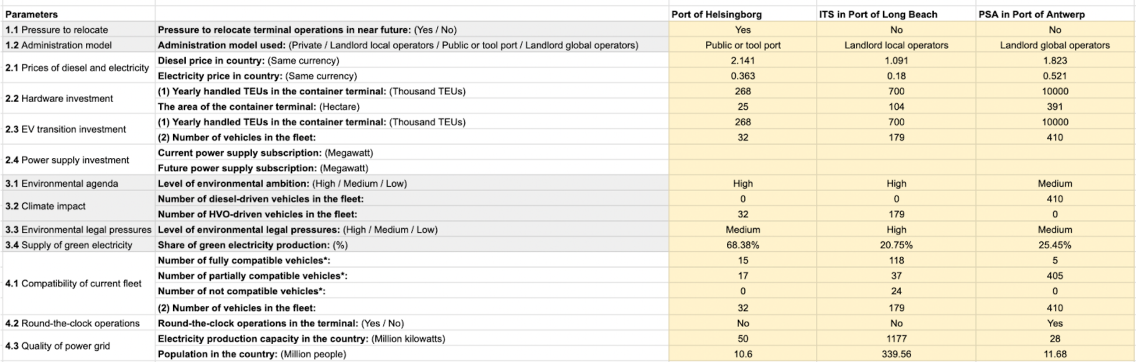
7 Tool pilot test

In this chapter, a pilot test of the tool developed in chapter 6 was carried out. The pilot test aimed to demonstrate an example of how the tool can be used, how information can be collected from different public and private sources, and how the tool's generated results can be interpreted. Thus, the pilot test displays the tool's abilities, while also providing insights into the tool's strengths and weaknesses, enabling for identification of opportunities for improvement.

The pilot test was conducted from the perspective of an ERS developer on a selected number of container terminals. The considered container terminals in the pilot test were the container terminal in Port of Helsingborg, the International Transportation Service (ITS) container terminal in Port of Long Beach and the three PSA International (PSA) container terminals in Port of Antwerp. All container terminals included in this thesis were considered as potential candidates for the pilot test since prior communication had been established when creating the current overview in *section 4*. The prior communication formed an opportunity to facilitate and streamline the second round of data collection required for this pilot test. However, the selection was further refined to only include the three container terminals mentioned above. These were chosen based on their varying operational and geographical characteristics. The candidates differed significantly in terms of their operational size and organisational structure, and they are situated in different parts of the world, which leads to the stakeholders and the business environments being different for each considered container terminal. This selection allowed for a diversity in the results and a stronger emphasis on the differences that exist between container terminals.

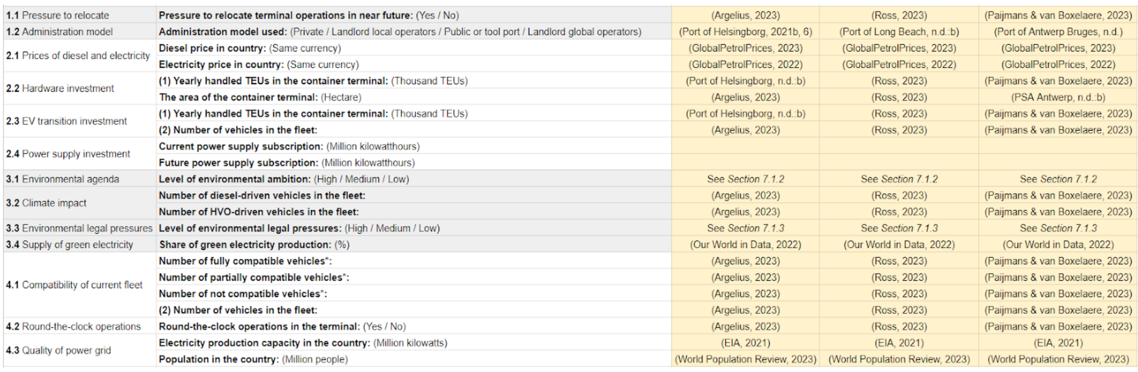
7.1 Input data and generation of parameter values

All data inserted in the tool were either found through public sources for the parameters stated as public or through interviews for the parameters stated as private. The input data appears in *figure 7.1* accompanied by the source of each input data in *figure 7.2*.



Parameters		**Port of Helsingborg**	**ITS in Port of Long Beach**	**PSA in Port of Antwerp**
1.1 Pressure to relocate	**Pressure to relocate terminal operations in near future:** (Yes / No)	Yes	No	No
1.2 Administration model	**Administration model used:** (Private / Landlord local operators / Public or tool port / Landlord global operators)	Public or tool port	Landlord local operators	Landlord global operators
2.1 Prices of diesel and electricity	**Diesel price in country:** (Same currency)	2.141	1.091	1.823
	Electricity price in country: (Same currency)	0.363	0.18	0.521
2.2 Hardware investment	**(1) Yearly handled TEUs in the container terminal:** (Thousand TEUs)	268	700	10000
	The area of the container terminal: (Hectare)	25	104	391
2.3 EV transition investment	**(1) Yearly handled TEUs in the container terminal:** (Thousand TEUs)	268	700	10000
	(2) Number of vehicles in the fleet:	32	179	410
2.4 Power supply investment	**Current power supply subscription:** (Megawatt)			
	Future power supply subscription: (Megawatt)			
3.1 Environmental agenda	**Level of environmental ambition:** (High / Medium / Low)	High	High	Medium
3.2 Climate impact	**Number of diesel-driven vehicles in the fleet:**	0	0	410
	Number of HVO-driven vehicles in the fleet:	32	179	0
3.3 Environmental legal pressures	**Level of environmental legal pressures:** (High / Medium / Low)	Medium	High	Medium
3.4 Supply of green electricity	**Share of green electricity production:** (%)	68.38%	20.75%	25.45%
4.1 Compatibility of current fleet	**Number of fully compatible vehicles*:**	15	118	5
	Number of partially compatible vehicles*:	17	37	405
	Number of not compatible vehicles*:	0	24	0
	(2) Number of vehicles in the fleet:	32	179	410
4.2 Round-the-clock operations	**Round-the-clock operations in the terminal:** (Yes / No)	No	No	Yes
4.3 Quality of power grid	**Electricity production capacity in the country:** (Million kilowatts)	50	1177	28
	Population in the country: (Million people)	10.6	339.56	11.68

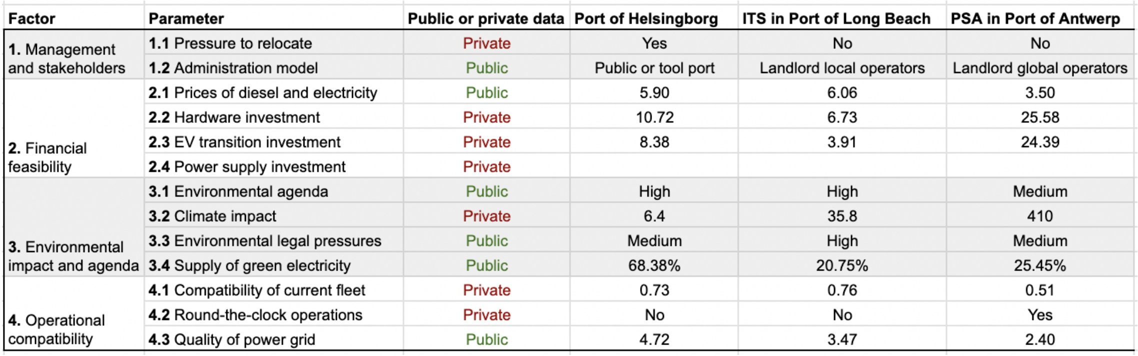
Figure 7.1: Input data for the pilot test



1.1 Pressure to relocate	**Pressure to relocate terminal operations in near future:** (Yes / No)	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
1.2 Administration model	**Administration model used:** (Private / Landlord local operators / Public or tool port / Landlord global operators)	(Port of Helsingborg, 2021b, 6)	(Port of Long Beach, n.d.:b)	(Port of Antwerp Bruges, n.d.)
2.1 Prices of diesel and electricity	**Diesel price in country:** (Same currency)	(GlobalPetrolPrices, 2023)	(GlobalPetrolPrices, 2023)	(GlobalPetrolPrices, 2023)
	Electricity price in country: (Same currency)	(GlobalPetrolPrices, 2022)	(GlobalPetrolPrices, 2022)	(GlobalPetrolPrices, 2022)
2.2 Hardware investment	**(1) Yearly handled TEUs in the container terminal:** (Thousand TEUs)	(Port of Helsingborg, n.d.:b)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
	The area of the container terminal: (Hectare)	(Argelius, 2023)	(Ross, 2023)	(PSA Antwerp, n.d.:b)
2.3 EV transition investment	**(1) Yearly handled TEUs in the container terminal:** (Thousand TEUs)	(Port of Helsingborg, n.d.:b)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
	(2) Number of vehicles in the fleet:	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
2.4 Power supply investment	**Current power supply subscription:** (Million kilowatthours)			
	Future power supply subscription: (Million kilowatthours)			
3.1 Environmental agenda	**Level of environmental ambition:** (High / Medium / Low)	See *Section 7.1.2*	See *Section 7.1.2*	See *Section 7.1.2*
3.2 Climate impact	**Number of diesel-driven vehicles in the fleet:**	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
	Number of HVO-driven vehicles in the fleet:	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
3.3 Environmental legal pressures	**Level of environmental legal pressures:** (High / Medium / Low)	See *Section 7.1.3*	See *Section 7.1.3*	See *Section 7.1.3*
3.4 Supply of green electricity	**Share of green electricity production:** (%)	(Our World in Data, 2022)	(Our World in Data, 2022)	(Our World in Data, 2022)
4.1 Compatibility of current fleet	**Number of fully compatible vehicles*:**	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
	Number of partially compatible vehicles*:	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
	Number of not compatible vehicles*:	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
	(2) Number of vehicles in the fleet:	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
4.2 Round-the-clock operations	**Round-the-clock operations in the terminal:** (Yes / No)	(Argelius, 2023)	(Ross, 2023)	(Paijmans & van Boxelaere, 2023)
4.3 Quality of power grid	**Electricity production capacity in the country:** (Million kilowatts)	(EIA, 2021)	(EIA, 2021)	(EIA, 2021)
	Population in the country: (Million people)	(World Population Review, 2023)	(World Population Review, 2023)	(World Population Review, 2023)

Figure 7.2: The source for each input data

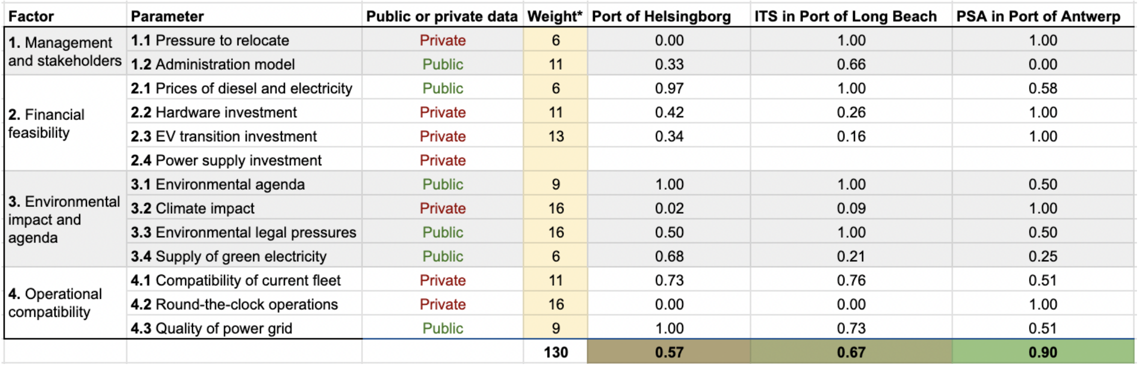
Subsequently, all input data were processed and calculated to generate values for each included parameter in the tool in accordance to *figure 6.2* which led to the results shown in *figure 7.3*.



Factor	Parameter	Public or private data	Port of Helsingborg	ITS in Port of Long Beach	PSA in Port of Antwerp
1. Management and stakeholders	**1.1** Pressure to relocate	Private	Yes	No	No
	1.2 Administration model	Public	Public or tool port	Landlord local operators	Landlord global operators
2. Financial feasibility	**2.1** Prices of diesel and electricity	Public	5.90	6.06	3.50
	2.2 Hardware investment	Private	10.72	6.73	25.58
	2.3 EV transition investment	Private	8.38	3.91	24.39
	2.4 Power supply investment	Private			
3. Environmental impact and agenda	**3.1** Environmental agenda	Public	High	High	Medium
	3.2 Climate impact	Private	6.4	35.8	410
	3.3 Environmental legal pressures	Public	Medium	High	Medium
	3.4 Supply of green electricity	Public	68.38%	20.75%	25.45%
4. Operational compatibility	**4.1** Compatibility of current fleet	Private	0.73	0.76	0.51
	4.2 Round-the-clock operations	Private	No	No	Yes
	4.3 Quality of power grid	Public	4.72	3.47	2.40

Figure 7.3: The results for each parameter from processing all input data

Consequently, all generated values were transformed into a unified format to be able to reach a final score for each considered container terminal. Qualitative values were quantified, and quantitative values were transformed into values between 0 and 1. Further, since the pilot test was conducted in the perspective of an ERS developer, the weighting was carried by the Vice President of Business Development and Strategy at Elonroad, who allocated the 130 available shares based on what he considered most important, *see figure 7.4*. Some parameters were weighted lower as their relevance was applied to a global warming perspective rather than from Elonroad's higher prioritised business perspective. Furthermore, laws and policies were considered more decisive compared to the container terminals' relatively ambiguous agendas and pressures from stakeholders. Lastly, intensity of operations, including fleet size and round-the-clock operations, was considered important when Elonroad conducted the weighting, as higher intensity would strengthen Elonroad's business case for selling their ERS solution. Based on this weighing and the transformed values, a final score for each considered container terminal was generated, see *figure 7.4*.



Factor	Parameter	Public or private data	Weight*	Port of Helsingborg	ITS in Port of Long Beach	PSA in Port of Antwerp
1. Management and stakeholders	**1.1** Pressure to relocate	Private	6	0.00	1.00	1.00
	1.2 Administration model	Public	11	0.33	0.66	0.00
2. Financial feasibility	**2.1** Prices of diesel and electricity	Public	6	0.97	1.00	0.58
	2.2 Hardware investment	Private	11	0.42	0.26	1.00
	2.3 EV transition investment	Private	13	0.34	0.16	1.00
	2.4 Power supply investment	Private				
3. Environmental impact and agenda	**3.1** Environmental agenda	Public	9	1.00	1.00	0.50
	3.2 Climate impact	Private	16	0.02	0.09	1.00
	3.3 Environmental legal pressures	Public	16	0.50	1.00	0.50
	3.4 Supply of green electricity	Public	6	0.68	0.21	0.25
4. Operational compatibility	**4.1** Compatibility of current fleet	Private	11	0.73	0.76	0.51
	4.2 Round-the-clock operations	Private	16	0.00	0.00	1.00
	4.3 Quality of power grid	Public	9	1.00	0.73	0.51
			130	**0.57**	**0.67**	**0.90**

Figure 7.4: The transformed final values for each parameter and overall score for each considered container terminal

Certain parameters require further clarification on how their values were generated. These are the parameters that require a reasoning approach, i.e. parameter *3.1 Environmental agenda* and *3.3 Environmental legal pressures*, and the parameters which had to be excluded due to insufficient availability of information, i.e. parameter *2.4 Power supply investment*.

7.1.1 Excluding parameter 2.4 Power supply investment

It became apparent that the availability of information on container terminal's current power supply subscriptions was not always accessible. Certain considered terminals could provide the required information, while others could not. Further, during the initial contact, some respondents were not completely clear on the information that was being requested. For instance, some individuals confused their current power supply subscription with transformer intake or similar. This required additional time-consuming clarifications to finally obtain the information sought. Additionally, each container terminal in a port did not necessarily have its own power supply subscription, as sometimes the entire port could have a common subscription on which all port operations relied. This further complicated the collection of this data. Due to the absence of data on the current power supply subscription, it was not possible to calculate the future power supply subscription. However, if the information would have been available, the method for estimating future power supply subscription would have been based on *formula 1* presented in *section 6.1.2*. As a result, parameter *2.4 Power supply investment* had to be excluded from the pilot test.

7.1.2 Evaluating parameter 3.1 Environmental agenda

One possible approach to evaluate and compare parameter *3.1 Environmental agenda* for the three container terminals, was to begin by examining how they showcase their environmental goals and aspirations on their communication channels. This emphasised their motivation and efforts to communicate their environmental commitment to the public. The channels encompassed websites, sustainability reports, and press releases. Port of Helsingborg clearly demonstrated their environmental vision and mission by having easily accessible information on their website and by publishing an extensive sustainability report annually (Port of Helsingborg, No date:a; Port of Helsingborg, 2021b, 17-37). The PSA container terminals in Port of Antwerp also clearly showcased their environmental vision and mission on their website by listing several environmental initiatives being done and by providing several press releases on the progress of their efforts. Furthermore, the parent company PSA International has published a sustainability report involving all its terminals around the world (Port of Antwerp Bruges, 2022, 44-47; PSA Antwerp, No date:a; PSA International, 2022). The ITS container terminal in Port of Long Beach provided limited exposure to their environmental work on the website and has not published any sustainability reports. However, the Port of Long Beach as a whole provided comprehensive information on their website about their current environmental initiatives within the port and highlighted the progress made for each initiative (Port of Long Beach, n.d.:a; ITS, n.d.). The ambitious environmental agenda advocated by the entire Port of Long Beach was assumed to be applicable to every container terminal operating within the port as well, thus making the environmental agenda for the ITS container terminal as ambitious as the one for the Port of Long Beach.

In addition to examining the way each container terminal communicated its environmental efforts, it was beneficial to evaluate the level of ambition of the actual goals and initiatives being communicated. The objectives and efforts that demand significant changes to the container terminal's operations and had a potential substantial positive impact on the environment were deemed as more ambitious. Another aspect considered in this examination was whether all the major environmental emissions found in container terminals were addressed in their objectives. This included CO_2

emission, air pollutants, and noise and light pollution. The Port of Helsingborg aimed to achieve zero net greenhouse gas emissions by 2035. The port was taking major steps in reaching this goal by transitioning to a container handling fleet free from fossil fuels by 2024. This requires substantial transitions in operations and major investments. The port's annual sustainability report primarily focused on goals related to CO_2 emission and noise pollution, with less attention given to concerns regarding air pollution (Port of Helsingborg, 2021b, 17-37). The PSA container terminals in Port of Antwerp have set objectives to reduce their CO_2 emission by 35 percent until 2030 along with 50 percent reductions of air pollution. Compared to the Port of Helsingborg, these targets were somewhat less ambitious which in turn was reflected in their environmental initiatives. PSA outlined various initiatives to enhance environmental sustainability in their operations, although many of them appeared to be relatively small. They were currently aiming at electrifying the entire fleet of forklifts and quay cars in the terminals, but there was no mention of remaining container handling vehicles in the fleet being electrified. Overall, their environmental objectives and initiatives mainly focused on CO_2 emission and air pollution, leaving noise and light pollution less mentioned (PSA Antwerp, n.d.:a). Finally, ITS and the Port of Long Beach have established several programs and objectives aimed at decreasing their emissions, including the complete transition of all terminal equipment and on-road trucks to zero emission by 2035. This requires substantial transitions in operations and major investments. While the port has placed significant emphasis on reducing air pollution and CO_2 emission, it has not addressed noise or light pollution (Port of Long Beach, n.d.:a; ITS, n.d.).

All three container terminals clearly communicated their environmental goals and initiatives although with slightly different approaches. None of the three container terminals addressed all the major types of emissions existent in container handling operations today. Both ITS in the Port of Long Beach and the container terminal in the Port of Helsingborg had the goal of achieving net zero or zero emissions by 2035 while PSA had the slightly less ambitious goal of reducing CO_2 emission by 35 percent and air pollution by 50 percent by 2030. The ambition level of the goals was reflected in the initiatives taken in each container terminal, which tended to be more large-scale and ambitious as goals become more extensive. Therefore, both ITS and the Port of Helsingborg were considered to have a “High” environmental agenda whilst PSA was considered to have a “Medium” environmental agenda.

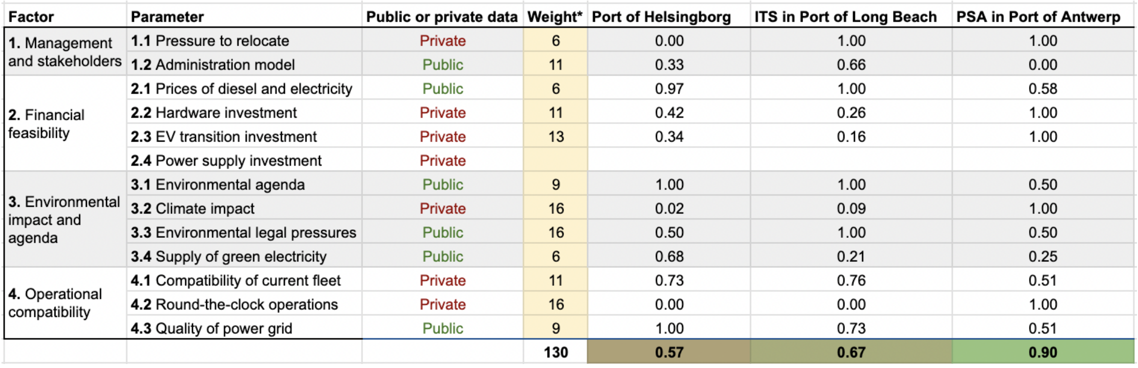
7.1.3 Evaluating parameter 3.3 Environmental legal pressures

When evaluating parameter *3.3 Environmental legal pressures*, it became apparent that the laws and regulations that applied to the three container terminals under consideration were often not strict requirements, but rather guidelines and goals to relate to. Starting off with the Port of Helsingborg and PSA in the Port of Antwerp, both these ports are situated in countries that are members of the EU. These container terminals must therefore comply with international laws and regulations set by the EU. This included the long-term goal of climate neutrality by 2050, and the interim goal of a 55 percent reduction in greenhouse gases by 2030 compared to 1990 (European Council, 2023). As a result, a big share of the goals and ambitions defined and followed by terminals were based on national policies in line with these common EU objectives. In addition, the Port of Helsingborg was also affected by several ambitious initiatives and policies created by the city of Helsingborg. This included a climate and energy plan featuring several future objectives, including an 85 percent reduction in greenhouse gas emissions by 2035 in relation to 1990, aligning with Sweden’s climate objectives (City of Helsingborg, 2018, 4-6). Finally, the ITS container terminal in the Port of Long Beach, which was not subject to EU regulations, was currently facing legal pressure from other sources. The state of California has the long-term goal of achieving net zero carbon pollution by no later than 2045 (Government of California, 2023). Additionally, more stringent and short-term targets stated by CARB, have made the Port of Long Beach and the Port of Los Angeles develop the *Clean Air Action Plan*, an air quality plan established to reduce port-related air pollution and its related health risks. Included in this plan, was the subgoal of transitioning to 100 percent zero emission cargo handling equipment by 2030 (Ross, 2023; CAPA, n.d.).

In summary, all three container terminals in the pilot test were subject to similar long-term country or state level environmental objectives to achieve climate neutrality. However, ITS in the Port of Long Beach also experienced short-term pressures more specifically related to port operations. The Port of Helsingborg and PSA in the Port of Antwerp were both part of the EU climate policy, thus being subject to similar national environmental legal pressures but possibly slightly different local legal pressures. Therefore, ITS in the Port of Long Beach was considered to have “High” environmental legal pressures while The Port of Helsingborg and PSA in the Port of Antwerp was considered to have “Medium” environmental legal pressures.

7.2 Generated results from the tool pilot test

The results from the pilot test as presented in *figure 7.4* shows that the PSA container terminals in Port of Antwerp receive the overall highest score of 0.90 compared to 0.67 for the ITS container terminal and 0.57 for the Port of Helsingborg. This rather superior result for the PSA container terminals indicates that this candidate has the most suitable conditions and greatest motives among the three for implementing an ERS. Since the pilot test was conducted from the perspective of an ERS developer, the result suggests that the developer should focus their marketing efforts on the PSA container terminals and put less effort into the two subsequently considered container terminals.



Factor	Parameter	Public or private data	Weight*	Port of Helsingborg	ITS in Port of Long Beach	PSA in Port of Antwerp
1. Management and stakeholders	**1.1** Pressure to relocate	Private	6	0.00	1.00	1.00
	1.2 Administration model	Public	11	0.33	0.66	0.00
2. Financial feasibility	**2.1** Prices of diesel and electricity	Public	6	0.97	1.00	0.58
	2.2 Hardware investment	Private	11	0.42	0.26	1.00
	2.3 EV transition investment	Private	13	0.34	0.16	1.00
	2.4 Power supply investment	Private				
3. Environmental impact and agenda	**3.1** Environmental agenda	Public	9	1.00	1.00	0.50
	3.2 Climate impact	Private	16	0.02	0.09	1.00
	3.3 Environmental legal pressures	Public	16	0.50	1.00	0.50
	3.4 Supply of green electricity	Public	6	0.68	0.21	0.25
4. Operational compatibility	**4.1** Compatibility of current fleet	Private	11	0.73	0.76	0.51
	4.2 Round-the-clock operations	Private	16	0.00	0.00	1.00
	4.3 Quality of power grid	Public	9	1.00	0.73	0.51
			130	**0.57**	**0.67**	**0.90**

Figure 7.4: The transformed final values for each parameter and overall score for each considered container terminal

Reviewing the scores for each parameter individually reveals that the PSA container terminals perform far better on certain parameters compared to the other candidates. This superiority in specific parameters forms the foundation for their higher overall score. As presented in the input data in *figure 7.1*, there are major differences in the number of handled containers per year between the candidates, which appeared to have given the PSA container terminals, handling the biggest amount of containers annually, a great advantage in the pilot test. Parameter *3.2 Climate impact* is based on the number of vehicles having to be electrified, which in turn is linked to the number of containers handled yearly as more handled containers require a bigger fleet of vehicles. Thus, handling more containers annually will result in a higher score on this parameter as there are more vehicles needing to be electrified, which will have a greater climate impact. This explains the PSA container terminals' superior score for this parameter as shown in *figure 7.4*.

Further, based on the input data presented in *figure 7.1*, the PSA container terminals are found to handle a significantly larger number of containers annually, while also keeping both the area of the container terminals and the number of container handling vehicles at relatively low levels. As a result, the PSA container terminals prove to have both better vehicle and space efficiency compared to the other candidates. This appeared to have given the PSA container terminals an additional advantage in the pilot test. For instance, for parameter *4.2 Round-the-clock operations*, a higher vehicle efficiency is linked with a greater tendency for adopting round-the-clock operations. This gives the PSA container terminals, having the highest vehicle efficiency, a particular advantage as they are more likely to have round-the-clock operations. This is clearly reflected in the PSA container terminals' superior score for this parameter as shown in *figure 7.4*. Further, it also turns out to be an advantage for parameters *2.2 Hardware investment* and *2.3 EV transition investment* where a higher space and vehicle efficiency makes the investment of implementing an ERS less significant. Handling a greater amount of goods generates more revenue. For space efficiency, handling this greater amount of goods in the same amount of area results in keeping the investment cost for ERS hardware down as the same amount of rail will be required to cover a sufficient share of all roads. For vehicle efficiency, handling this greater amount of goods with the same number of vehicles results in keeping the EV transition cost down as the number of vehicles needing to undergo an electrification can be kept down. Consequently, achieving better space and vehicle efficiency leads to increased revenue while maintaining investment costs at similar levels, thereby reducing the significance of a large-scale investment in ERS. This improved space and vehicle efficiency is clearly reflected in the PSA container terminals' superior score for parameters *2.2 Hardware investment* and *2.3 EV transition investment* as presented in *figure 7.4*.

The last parameter worth addressing for the PSA container terminals is the parameter *1.2 Administration model*. In this case, the PSA container terminals have received a low score rather than a high score, see *figure 7.4*. As stated in the input values of *figure 7.1*, this candidate has adopted the landlord port model and is runned by a global operator. This administration model involves several stakeholders and high levels of bureaucracy. In the short term, this is considered less desirable as it corresponds to longer lead times for making investment decisions. However, if the ERS developer manages to successfully sell and implement an ERS in these container terminals, opportunities could open for additional sales to the global operator's additional container terminals around the world.

In addition to commenting on the PSA container terminal's distinctive results, a more general observation was made. Certain parameters seemed to be influenced by the geographical position in which the container terminal was operating in. This included parameter *2.1 Prices of diesel and electricity, 3.3 Environmental legal pressure, 3.4 Supply of green electricity* and *4.3 Quality of power grid*. Despite obtaining the lowest overall score in the pilot test, Port of Helsingborg being located in Sweden, received remarkably high scores for all of these parameters compared to the other candidates. This suggests that there may be location-based advantages to gain for container terminals having a favourable geographical position. Directing attention towards container terminals with these geographic advantages can facilitate the identification of additional candidates with comparable locational advantages but with better performance in other parameters, leading to finding new terminals with an overall higher score.

8 Tool pilot test discussion

This chapter discusses the use of the tool during the pilot test. Key takeaways are presented along with suggested tool improvements and possible application areas.

8.1 Key takeaways from using the tool

Previous communication had been established with the container terminals included in the pilot test, as these were also used when creating the current overview in *section 4*. This facilitated and streamlined the second round of data collection required for the pilot test. These container terminals differed significantly in terms of their operations and geographical location, allowing for a diversity in the results and a stronger emphasis on the differences that exist between today's container terminals. On the other hand, choosing the same container terminals as used in the data collection for the current overview posed a risk of reducing the usefulness of the pilot test. Using the same container terminals in the current overview and the pilot test could result in an impaired pilot test validity and a risk of missing potential conflicting insights useful to improve the framework. Nevertheless, it's worth noting that the parameters identified in the framework were not only based on the container terminals included in the pilot test but also on other container terminals, organisations within various industries, and theoretical literature. As such, the sample of container terminals is still considered appropriate for evaluating the tool's capabilities as none of their individual attributes were ever the sole basis in the creation of the tool.

8.1.1 Weighing the tool's complexity with its user-friendliness

A dilemma that has been present throughout the creation of the tool has been to find a balance between complexity and the ease and efficiency of use. Increased complexity would involve larger calculations and more extensive data collection. Therefore, more complexity provides more specific and accurate insights but decreases the tool's time efficiency and ability to be applied to a large number of container terminals. To find a suitable level of tool complexity was therefore essential to create a tool that could be used on a large scale and at the same time provide valuable and accurate insights. The pilot test was intended to provide an understanding of this balance in the created tool and to identify possible opportunities for improvements.

In the data collection of the pilot test, most of the parameters had easily accessible and up-to-date information. The use of public databases proved to be particularly effective in data collection, as these sources provided easily accessible data in a format compatible with the tool. On the other hand, the created tool proved to have some difficulties that prevented the tool from being as effective as first thought. Some of the privately collected data proved to be commercially sensitive for some of the considered container terminals, such as data on the number of yearly handled containers. Therefore, only rough estimations could be provided for some parameters. However, this was not considered to reduce the validity of the results as the tool was not intended to provide exact figures but only relative ones between the considered container terminals. Another difficulty that arose was the fact that some parts of the data collection were more time-consuming than initially thought. Specifically, the lead times for gathering information from respondents during the second round of interviews were longer than anticipated. Additionally, parameters such as *3.1 Environmental agenda* and *3.3 Environmental legal pressures*, which required a reasoning approach to reach a conclusion, required a more in-depth investigation, resulting in increased time consumption. Further, upon contacting each pilot tested container terminal, it became evident that, in some cases, a single respondent within the container terminal was not able to provide all the input data necessary to fully utilise the tool. The tool covers a wide range of areas, which can make it difficult for a single interviewee to provide answers within all the various areas covered by the tool. This may result in the tool becoming less time efficient as more than one interview may be required for each container terminal to ensure that all necessary information can be collected to fully utilise the tool. If time is limited, an alternative option to tackle this issue is to exclude the parameter from the tool altogether. This had to be done for parameter *2.4 Power supply investment* in the pilot test. In this case, interviewees were unable to provide sufficient information on current power supply subscriptions, information necessary to gain insights into parameter *2.4 Power supply investment.* Due to a restricted timeframe for this pilot test, this parameter needed to be excluded. Another challenge that arose was the inconsistency in the format of the data provided during the interviews. Some interviewees provided information applicable to the entire port, while others only provided information pertaining to the specific container terminal under consideration. To avoid obtaining misleading results, it proved to be important to bear in mind that the data collected should adhere to a uniform format across all the container terminals under consideration.

The calculations and analysis of the collected data were not intended to generate values in absolute terms, thus calculated results did not accurately represent reality. Instead, the values were calculated based on being in relation to the other considered container terminals. This approach improved the tool's user-friendliness as it allowed for simplified calculations while still generating the desired comparable insights. However, this simplified method did not allow users to extract a single parameter value for a specific container terminal, as the value only has meaning when compared to the other pilot tested container terminals. Further, after conducting all the necessary calculations and weighting each parameter, the parameter values could be summed up to generate a final score for each considered container terminal. This final score improved the tool's usability by enabling the user to easily identify the best suited container terminals for an ERS implementation. Additionally, the tool effectively demonstrated each parameter’s individual score, enabling users to understand the basis for the final score and to identify which parameters each container terminal was performing well and poorly in.

8.1.2 Influence of subjectivity in the usage of the tool

The tool was intended to allow for as little subjectivity in its use as possible. Therefore, the desired choice of method for generating each parameter value was to base it on objective and concrete information that could be directly used as input data in the tool. However, some parameters required a certain degree of subjectivity for a value to be generated. These values could not be determined based on concrete information and had to be derived through discussions and comparisons instead. This subjectivity posed a risk of generating parameter values that may not entirely reflect reality. Consequently, the values and insights derived from the tool may become misleading. This is especially apparent for parameters *3.1 Environmental agenda* and *3.3 Environmental legal pressures.* It is important to have this subjectivity in mind when using the tool and when extracting insights.

8.2 Tool improvements

The lead times for collecting the private data from interviews proved to be more time-consuming than initially thought when conducting the pilot test. Given that there already was an established contact with the container terminals included in the pilot test, it can be concluded that lead times are likely to be even longer for container terminals where no previous contact has been made. Hence, it would be useful to continue investigating how currently private data can be turned into public data to reduce the dependency on responses from interviewees. In addition to reducing lead times, turning more private data into public data would also minimise the risk of information not being available during interviews and reduce the need for conducting more than one interview per container terminal. Turning more private data into public data would also reduce the dependency on commercially sensitive data risking certain parameters to be excluded when using the tool.

The methods used for determining a value for the parameters requiring a reasoning approach are another area of potential improvement. These methods should be made more standardised to minimise the room for subjectivity and to make it less time-consuming to generate a parameter value. The standardisation of these methods can be improved by introducing more distinct and specific aspects to consider along with stricter criteria for what is considered high, medium and low.

8.3 Usefulness of the tool

The developed tool will be useful for ERS developing companies in different ways. Primarily, the tool will function as an easy-to-use tool for evaluating which container terminals are most suited for implementing an ERS. This allows for a more precise market scope as only the most suitable candidates can be focused on for further marketing efforts. The tool's second major benefit is derived from its layout as it showcases the most important aspects to consider when implementing an ERS. These aspects are compared between different considered container terminals, creating compelling arguments as to why a specific container terminal is especially suited for an ERS implementation. Benchmarking a container terminal using these aspects against its competitors, can thus be a useful tool when constructing sales pitches.

From the alternate usage perspective of container terminals and ports, the usefulness of the tool is slightly different. Container terminals in search of new ways of improving sustainability and streamlining their operation can use this tool to determine whether an implementation of an ERS is an appropriate way of electrifying their operations. Thus, this tool can provide insights into the suitability of an electrification with an ERS for a container terminal, while also emphasising which characteristics of the container terminal are considered more and less appropriate. The tool also allows for the container terminal to compare its compatibility with its main competitors, further confirming their compatibility of implementing an ERS.

9 Conclusions

The final chapter concludes the thesis by answering the research questions. It also highlights the theoretical and practical contributions of the research, limitations and suggestions for further research.

9.1 Answering the research questions

This section uses the insights discovered and presented throughout the thesis to answer the two research questions stated in *section 1.2* The research questions for this thesis are as follows:

RQ1: What factors need to be considered when implementing an Electric Road System in a port?
RQ2: How do ports differ in terms of how suited they are for an Electric Road System implementation based on the identified factors?

9.1.1 Answering RQ1

The ERS compatibility framework presented in *section 6.1* in *figure 6.1* provides the basis for answering this research question. The framework emphasised and highlighted the most essential aspects to acknowledge when implementing an ERS in a container terminal. This framework is believed to be extendable to also encompass a wider context of port operations as most of the insights generated during the research process, which formed the basis for the developed framework, were considered to be relevant across all port operations. The framework consisted of 13 parameters corresponding to the areas needed to be covered. These parameters were categorised into four overarching factors based on common characteristics to create a clear division between the included parameters. These factors and underlying parameters are presented below and answers **RQ1**:

- **Factor 1**: Management and stakeholders
    - **Parameter 1**: Does the port experience pressure from nearby city to relocate?
    - **Parameter 2**: Which administration model does the port apply?
- **Factor 2**: Financial feasibility
    - **Parameter 1**: What is the price of diesel and electricity in the country?
    - **Parameter 2**: How significant will the hardware investment be?
    - **Parameter 3**: How significant will the investment be for converting vehicles to electric equivalents?
    - **Parameter 4**: How significant will the investment be for upgrading current power supply subscriptions?
- **Factor 3**: Environmental impact and agenda
    - **Parameter 1**: How strong is the port's environmental agenda?
    - **Parameter 2**: To what extent will a transition from diesel-driven to electric-powered vehicles reduce climate impact?
    - **Parameter 3**: Does the port experience local environmental legal pressures?
    - **Parameter 4**: Is the supplied electricity produced in an environmentally friendly way?
- **Factor 4**: Operational compatibility
    - **Parameter 1**: Does the port have round-the-clock operations?
    - **Parameter 2**: What is the quality of the country's power grid?
    - **Parameter 3**: Will the current fleet of vehicles be compatible with an ERS?

9.1.2 Answering RQ2

The pilot test conducted in *section 7* provides the basis for answering the second research question. The pilot test revealed that all the factors and parameters listed above differed among the various container terminals under consideration. Ports proved to be managed in different ways with varying numbers of stakeholders involved. The financial feasibility of implementing an ERS turned out to differ, primarily driven by variations in investment significance and operating costs. Ports proved to have various potential to reduce their environmental impact due to varying environmental agendas and pressure from local stakeholders. Furthermore, ports proved to have varying operational compatibility for an ERS, mainly driven by the current fleet's compatibility to an ERS. These differences highlight that there are significant variations in port operations and varying levels of feasibility for implementing an ERS in these operations.

In addition to the observed differences in the factors and parameters between ports, some more general observations, having an impact across several parameters, were also identified. Space efficiency and vehicle efficiency proved to be important elements for determining the significance of the investments required when implementing an ERS. Improved space and vehicle efficiency allow for a greater amount of goods to be handled, thus increasing revenue, while having the same operating area and the same number of vehicles handling the goods. For space efficiency, handling a greater amount of goods in the same amount of area results in keeping the investment cost for ERS hardware down as the same amount of rail will be required to cover a sufficient share of all roads. Similarly for vehicle efficiency, handling a greater amount of goods with the same number of vehicles results in keeping the EV transition cost down as the same amount of vehicles needs to undergo electrification. Therefore, having an increased revenue while keeping investment costs on similar levels results in reduced significance of a large-scale investment in ERS. Furthermore, increased space and vehicle efficiency of a port also appeared to be linked to a greater tendency for adopting round-the-clock operations. This is an especially important attribute for ports to possess from the perspective of an ERS developer, as it gives the use of an ERS additional operational advantages, thus an additional selling point for the ERS developer.

The suitability of implementing an ERS further proved to be influenced by the geographical position in which the port was operating. A port could become more suitable for an ERS implementation solely based on its more favourable local fuel market, local power grid and local legal pressures. Thus, the geographical position of ports becomes an additional, more general, aspect which can explain how ports differ in terms of how suited they are for an ERS implementation. Directing attention towards ports with these geographic advantages can facilitate the identification of additional candidates with comparable locational advantages but with better performance in other parameters.

9.2 Evaluating the utilisation of adopted methodology theory

Linking the two previously unrelated topics of ERS and container terminals required large amounts of information to be collected, some of which was intended to create a basic understanding rather than being directly useful in later stages of the study when the framework and tool was created. To extract the key takeaways required for subsequent parts of the thesis, the SWOT analysis framework was used for understanding ERS and a modified version of the PESTEL framework was used for understanding container terminals. These frameworks' beneficial breakdowns and categories facilitated the compilation of the large amount of information being presented in *section 4* and enabled for the key takeaways to be visualised.

Upon evaluation, it can be concluded that both frameworks fulfilled their intended purpose of identifying key takeaways relevant to the subsequent sections of the study. The key takeaways presented in these frameworks provided the basis for both the additional limitations made in *section 5*, and for the conducted analysis made to investigate an implementation of ERS in container terminals. Additionally, the modification of the PESTEL framework where the technological aspect was replaced with the more comprehensive operational aspect, proved to be very useful. It opened for further understanding of container terminals and, also turned out to be one of the four overarching factors included in the later developed framework.

9.3 Contribution

This thesis has made contributions in both theoretical and practical aspects. Theoretically, this study linked the two previously unrelated topics of ports, with a particular focus on container terminals, and ERS, to gain insights into their interrelated dynamics. Specifically, the research investigated the implementation process of an ERS in a container terminal, an area where little to no research has been conducted before. Moreover, given that container terminals are a type of closed-looped transport system, this thesis has also contributed to the broader area of ERS implementations in closed-looped transport systems. Practically, this thesis has contributed by introducing a framework that outlines key aspects to consider when implementing an ERS in various container terminals. The generability of the framework allows it to also be relevant for other types of port operations. By using this framework, it is possible to map the varying conditions and implications for container terminals to implement an ERS and identify the areas where the differences are most significant. This tool's versatility allows it to serve both ERS developers seeking the most suitable ports to market their solutions to, and port operators wanting to assess how suitable their operations are for an ERS implementation and compare their compatibility with their primary competitors.

9.4 Limitations

In the early stages of the research process, delimitations were introduced to gain a sufficient scope suited for the timeframe of this thesis. One of these delimitations was to solely focus on investigating an ERS implementation in one type of port operation, container terminals. As the purpose of this thesis was to investigate an ERS implementation in an entire port, it raised some concerns on whether the later developed framework could be applicable to other port operations as well. However, most of the insights generated during the research process, which formed the basis for the developed framework, were considered to be relevant across all port operations. Additionally, the developed framework aimed at being applicable for all types of port operations with included parameters all being relevant across all types of port operations. On the other hand, the subsequently developed tool was more adapted to only be used in container terminals as certain data points were solely applicable to container terminals. However, the transparency and user-friendliness of the tool allow for easy adaptations and changes of data points to suit the use of the tool with other types of port operations. In summary, both research questions of this thesis were stated at a port-wide level whilst the research of this thesis, formed by delimitations, was at a container terminal-wide level. Even if this was the case, the specific focus on container terminals was considered to have contributed to a deeper understanding compared to having considered all port operations. This more in-depth understanding of one type of port operation made it possible to answer the more general research questions while also being able to provide more in-depth examples of the complex nature of implementing an ERS.

Further, an implementation of an ERS is a vast topic that encompasses several different aspects as revealed through the numerous readings and interviews conducted. To gain an even more in-depth understanding, the thesis could have narrowed the scope to only focus on a few specific aspects concerning the implementation of an ERS in a port. However, due to the technology's novelty and insufficient prior research, formulating more specific research questions was challenging. Therefore, an alternative approach was adopted with the goal of creating a comprehensive understanding covering all aspects needed to have in mind when implementing an ERS. Nevertheless, the research questions were considered niche enough, as the thesis achieved adequate depth to contribute both theoretically and practically.

Another possible limitation was the rapidly evolving nature of the ERS technology which is soon to reach a more large-scale commercialisation. The research was based on the current maturity of the technology and therefore, it was uncertain for how long the provided information, on which the framework was created, stays up to date. However, the framework includes parameters considered to withstand future changes, thus ensuring their continued relevance as technology advances. Additionally, the framework has the ability to be kept updated by adjusting it as new information and breakthroughs within the technology occur.

9.5 Suggestions for further research

During the study, it became evident that there is still much to explore in this area. As a result, three main areas for further research were identified.

Firstly, additional research should be conducted to properly validate the framework's ability to be applicable to other port operations beyond container terminal operations. Even though many insights generated from the research proved to be common for all the different types of port operations, more evidence is required to support these findings. Further, despite being tailored for container terminals, it is believed that the framework’s generic parameters can be applied to several different closed-looped transportation systems. However, further research is needed to corroborate these findings. It would therefore be beneficial to investigate the framework's potential to be applied to other closed-loop transportation systems sharing similar attributes to ports.

Another area for further research concerns the level of depth of the data collection and analysis. The aim of this thesis was to create a comprehensive understanding of the dynamic of the two previously unrelated topics of ERS and ports, at the expense of not covering each aspect too deeply. A next step could therefore be to explore all covered aspects even more thoroughly. For instance, conducting more extensive research on the legal aspects of implementing an ERS may involve consulting a legal expert to gain a more comprehensive understanding of the complex nature of laws and regulations concerning an ERS implementation. By doing this, new relevant perspectives could be identified which could lead to better ways to evaluate each parameter, or the inclusion of new parameters.

A final area for further research is linked to the mentioned fact that ERS is an emerging technology soon to reach a greater scale of commercialisation. As the technology gradually develops, new opportunities are created for how ERS can be implemented in various closed-looped systems, including container terminals. Thus, ongoing research would be favourable to adapt the framework to the latest information since this could alter the system's requirements or the potential benefits that ERS can provide. Additionally, this would contribute to maintaining the reliability of this thesis’ findings.

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10.3 Interview subjects

Alaküla, Mats; Professor within Industrial Electrical Engineering and Automation at Lund University. 2023. Interview 21 February.

Argelius, Christina; Chief Technology Officer at Port of Helsingborg. 2023a. Interview 24 February and 25 April.

Johansson, Per-Erik; Technology Manager Electrification at Kalmar Mobile Solutions. 2023. Interview 23 February.

Kalman, Björn; Researcher within Road and Rail Technology at Swedish National Road and Transport Research Institute. 2023. Interview 21 February.

Löthner, Per; District Manager at N.C. Nielsen. 2023. Interview 3 March.

Magnusson, Cecilia; Chairman of the Board at the port of Gothenburg. 2023. Interview 27 February.

Paijmans, Bart; Sustainability Manager at Antwerp Terminal Services & van Boxelaere, Toon; Sustainability Engineer at PSA Antwerp. 2023. Interview 3 March and 12 April.

Palmqvist, Anna; Queen of Production at Elonroad. 2023. Interview 13 February.

Ross, Halfdan; Chief Project Officer at International Transportation Service in port of Long Beach, Los Angeles. 2023. Interview 2 March and 7 April

Sjöstrand, Henrik; Researcher within Maritime at Swedish National Road and Transport Research Institute. 2023. Interview 1 March.

Stemmler, Lars; Head of Bremenports Int. 2023. Interview 1 March.

Torstensson, Anton; VP Business Development & Strategy at Elonroad. 2023. Interview 20 February.

A. Appendix

A.1 Vehicles used in a container terminal

AGV, Automated Guided Vehicle
(Konecranes, No date)

Empty Container Handler
(Kalmar, No date:c)

Reachstacker
(Kalmar, No date:c)

RMG, Rail-Mounted Gantry Crane
(Konecranes, No date)

RTG, Rubber-Tired Gantry Crane
(Konecranes, No date)

Shuttle Carrier
(Kalmar, 2021)


Straddle carrier
(Kalmar, No date:c)


STS, Ship-To-Shore Crane
(Kalmar, No date:c)


Terminal Tractor
(Kalmar, No date:c)

Top Handler
(Kalmar, No date:d)

A.2 Interview guides

The following are the main scripts used for the different interviews. Depending on the respondent's background, interview guides were customised and additional questions were added. Further, a general introduction was included with a description of our thesis and other general formalities. Presented below are the four main types of interview scripts used.

A.2.1 Interview guide - Ports and container terminals

Overall facts:

- What kinds of port operations do you have today?
- What is the size of the container terminal?
    - Number of containers handled yearly?
    - Number of ship arrivals yearly?

Operations:

- What is the journey of a container from the moment it arrives on a ship until it is loaded onto a train, boat or truck for further transport?
    - How does this activity differ between different sizes of ports?

- What vehicles are generally used in a container terminal fleet today?
    - What is the purpose of the different vehicles?
    - Why have these particular vehicles been chosen?
    - How does the distribution of different types of vehicles look?
    - What is the utilisation rate of the vehicles today?
        - During what hours of the day are they operating?
    - How are these vehicles powered/fuelled?
        - How does the refuelling work and how is the fuelling station structured?

- Electrification
    - How far in the electric development are you?
        - Are the fleet electrified?
        - How big is your energy consumption today?

        - Is the port producing its own electricity?
    - What advantages and disadvantages do you see with the electrification of port operations?

- Are there any apparent driving patterns for the vehicles in the port?
    - Is there a clear main route where vehicles travel more frequently?
    - Are there fixed points where containers are unloaded from boats and picked up by vehicles?

Economics:

- What are the main expenses of a port?
    - Is fuel consumption a big expense in ports?

- What are the main sources of income for a port?

- Do you have the financial capacity to make major investments? E.g. in an ERS solution

Management of the port:

- What stakeholders are involved in port operations?
    - Who owns the port?
    - Who runs the container operations?
- Does this differ between ports?

- Which stakeholders are involved in the decision regarding investments?

- Do you have any KPI:s today for evaluating the performance of the port?

Laws and regulations:

- Are there laws and regulations affecting a port's operations?

- What laws and regulations do you think will be relevant to keep in mind if you were to implement a full-scale ERS solution?

    - Procurement issues due to ownership situation?

Environmental:

- What environmental impact does ports have today?
    - CO_2
    - Air pollutions
    - Noise
    - Closeness to city

- What measures have you taken to reduce your climate impact?

Socially:

- Are ports considered to be a dangerous place to work in?
    - What is being done to improve safety?

- Do you think an ERS solution could result in any reduced safety?

New port:

- We have heard about a couple of ports needing to be relocated in the near future to allow for the expansion of nearby cities, such as more housing. Is this something that has been discussed within your port?

- Is scarcity of space generally a problem for ports?

Other:

- Is there anything we missed to ask about that you think would be relevant for us to know?

A.2.2 Interview guide - Retailers of container handling vehicles

The fleet of vehicles in a port today:

- Which vehicles are present in a port today?
    - Is there any overall division/categorisation of vehicles?
    - What is the purpose of these?

- What does a vehicle fleet generally look like today? What is the composition of vehicles?
    - Does the vehicle fleet differ if you look at a small container port versus a large container port?
        - Differences in which vehicles are used?
        - Are there ports that do not use road bound vehicles at all?
    - Does the vehicle fleet in general differ depending on where in the world you look?
    - Why are specific vehicles chosen in specific situations?
        - E.g. what are the motives for having a reach stacker? Straddle carrier? Trucks? Terminal tractors?

- Is there any general relationship between the number of containers a port handles and the number of vehicles? → X number of containers per vehicle

Electrification of port vehicles:

- Which vehicles that you sell are electrified today?

- What is the general fuel used by container handling vehicles today?
    - Could you estimate the share of vehicles powered by fossil fuels?

- How much of your sales are electrically powered vehicles versus diesel-powered vehicles?
    - Do you see an increased demand for your electric vehicles versus your diesel vehicles?

- Where are your biggest markets for electric vehicles?
    - Are these based on geographical location?
    - Are these based on port size?

- Do you have plans to switch completely to producing only electric vehicles in the future?

Port vehicles compatibility with ERS:

- Which vehicles that you sell are compatible with the use of an ERS solution?
    - Which vehicles can place a pick-up on the underside that can have contact with the rail on the ground?
    - Which vehicles have a battery size that gets sufficient charge from the rail? (150-300 kW from the rail)

- What is your opinion on the potential for an ERS implementation in container ports?
    - Advantages
    - Disadvantages
    - Difficulties in implementation

Other:

Is there anything we have missed to address that you think may be relevant to our work?

A.2.3 Interview guide - Experts within ERS

Elonroad's ERS technology:

- What are the differences between the glued rail and the milled rail? Based on the following aspects
    - Road surface
    - Safety
    - Maintenance
    - Coherence with current vehicles and systems

- What are the benefits of the ERS solution's ability to collect data?
    - Vibration data?
    - Temperature and humidity data?
    - Detecting vehicles?
    - Communication between vehicles?

Implementation of ERS:

We have two different scenarios: (With the following aspects in mind: economic, social and environmental impacts)

1. Implementation of Elonroad's ERS in a closed system fuelled only by diesel?
    a. What benefits will the ERS bring?
    b. What disadvantages will arise from the ERS?
2. Implementation of the Elonroad's ERS in a closed system that is partially or fully electrified using charging posts?
    a. Which advantages will the ERS be able to contribute with?
    b. What disadvantages will arise from the ERS?

- What basic conditions need to be in place for a satisfying implementation of ERS in a closed system?

- With regards to the power supply, will there be a need for more capacity than what is available in a non-electrified closed system today?
    - What kind of equipment is required to create the desired power supply?
    - Are there countries that do not have a powerful enough electricity grid to power an ERS solution?

- Investment costs and operational costs with an ERS
    - What are the investment costs when implementing an ERS?
    - What are the costs once an ERS is installed and in use?
        - How do these differ from when the fleet runs on diesel instead?
        - How do these differ from when the fleet is powered by electricity and charged at charging points?

- Is there any share of the total road that must have coverage of ERS rails for the vehicles in the closed system to be able to get an "unlimited distance"?

Thoughts and input to our port tool:

- When we compare different ports around the world, what factors do you think will be most relevant to keep in mind?
    - That is, which factors are important?
    - Which factors will differ between countries?

Laws and regulations for ERS:

- Are there any defined laws for ERS today?
- Are there any defined standards for ERS today?
- Are there any subsidies for the implementation of ERS today?

Global perspective of ERS:

- Which countries are leading the development of ERS?
    - Where are the companies developing ERS?
    - Where is the technology most tested?
    - How do different countries interact in the development of the technology?
        - Can different developments create difficulties?
        - E.g, can the technology we evaluate become obsolete and thus not an attractive investment for the port?

Other:

Is there anything we have missed to address that you think may be relevant to our work?

A.2.4 Interview guide - Research institutes

Port infrastructure:

- What aspects are considered when designing the road infrastructure within a port?
    - Long straight roads where most vehicles will be travelling?
    - Does the structure of the road network change frequently?

- Which road surfaces are used in ports today?
    - What is the reason for the choice of material?
        - Durability
        - cost
        - Etc?
    - What about wear and tear on roads?
        - Does it lead to dangerous particles?

- How are ports' road networks linked to external transport?
    - For example, the road network and rail transport

- Where do ports place the refuelling stations?
    - Do they take up much space?

- Which vehicles operate within the port today?
    - What are the difficulties associated with the variety of vehicles within a port?

- Are there any specific differences in port infrastructure based on port size?

Implementation of ERS:

- If a port were to implement an ERS system, do you see any potential difficulties in installation?
    - Do you see any benefits? (short- and long-term)
    - Do you see any disadvantages? (short- and long-term)
    - What difficulties do you see in implementing an ERS solution?

- Which stakeholders do you think are usually involved when there are changes such as the implementation of ERS in a port?

Laws and policies:

- What are the policy objectives in Sweden for ports? Do you know any policy objectives globally?
    - Environmental?
    - Electrification?
    - Economic?

- What laws and regulations do you think would be relevant to keep in mind if a full-scale ERS solution were to be implemented?
    - Environmental, Safety, traffic authority

- We have read about ports having to be moved to make room for cities to expand. Do you think this is a trend we will see more of?
    - Are many ports today located close to cities?

- Policy instruments
    - Are there any support packages or tax breaks that ports can take advantage of if they were to convert to ERS because of its reduced climate impact?

Governance:

- Which stakeholders are involved in a port operation?
    - Who owns the port?
    - Who runs the container handling operations?

- What overall goals are there in ports today?
    - Do you see that more ports today are starting to focus on sustainability goals?
        - How are these sustainability goals weighed against having an economically favourable port operation?

- Are there any KPI:s that ports' performance is currently evaluated based on?

        - Do you see that more ports today are starting to address sustainability goals?
            - How are these sustainability goals weighed against having an economically favourable port operation?

The future:

- What are the future trends that ports are adapting to?
    - Which ones are relevant right now?
        - Electrification?
    - Which ones could potentially emerge?
        - Automation?
        - Digitalisation?

Other:

- Is there anything we have missed to address that you think may be relevant to our work?