Financial considerations along the Transportation chain of Battery Electrical Vehicles.

Master Thesis in Shipping and Maritime Technology.



Ashitosh Palkar

Paritosh Palkar

Chalmers School of Maritime Studies.

Chalmers University of Technology

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Ashitosh Palkar

Paritosh Palkar

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Examiner: Henrik Ringsberg, PhD / Associate Professor / University teacher Maritime Logistics

Supervisor: Henrik Ringsberg, PhD / Associate Professor / University teacher Maritime Logistics

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Chalmers University of Technology

Department of Mechanics and Maritime Sciences Division of Maritime Studies

412 96 Göteborg, Sweden

Abstract

The RoRo ports and terminals play a vital role in the supply chain of Automobile industry. For many decades RoRo ports and terminals have been a foundation firm in transportation of Internal combustion engine vehicles (ICEV). The relatively recent surge in demand for transportation of Battery Electric Vehicles (BEV) has triggered questions within the port and terminal sector about its preparedness and adaptability. Thus, this thesis researches the financial consideration associated with the transportation of Battery Electric vehicles (BEV´s) for ports and terminals perspective. The study focuses on assessing the costs related to three identified categories which are Logistic operations, Safety measures and Terminal Infrastructure that ports and terminals need to consider since the introduction and surge of BEV´s. For this a structured literature review was conducted and combined with a case study for a practical understanding of this study. Additionally, qualitative data formed a primary emphasis in this study. The empirical material in this research consists of interviews with terminal operators, RoRo shipping lines, and insurance specialists. In this thesis, the identification, suggestions and considerations of cost factors found in the published literature is compared with actual present costs for ports and terminals due to the BEVs revealing the similarities and differences. For each category a cost factors are identified. The findings in logistic operations of BEV´s showed that costs are limited in basic loading and discharging operations, as BEVs are generally handled in the same way as ICEV´s, but costs arise through organizational adjustments, technical roles, and selected training needed for familiarization and handling of BEV. In terms of safety costs, which are primarily associated with fire safety, there is a tendency to require increased spacing between BEVs, as well as additional investments in new or upgraded technologies and equipment for managing BEV fires. The immediate need to take on the safety costs is higher for shipping lines since vessels have confined spaces for cargo with less external assistance at sea while terminals tend to rely on operational routines, existing monitoring practices, and external emergency response which make this sector slower in implementing the safety costs for BEV. Financial impact on insurance premiums is presently indirect and is stabilizing as knowledge about BEV logistics is increasing. While Infrastructure costs were mainly linked to charging stations and the parking garages. In addition to the investment in the charging station, electricity costs, electricity demand, and grid capacity were considered. While for the parking spaces the cost for the structural implications due to heavier BEVs, especially in multi-storage parking facilities, were identified and furthermore the need for structural strengthening of parking spaces due to the nature BEV fires were highlighted. The study concludes that the financial impact for ports and terminals due to BEV´s is shaped by organizational changes and training in terms of logistic operations, safety preparedness and infrastructure adaptation. The proposed cost structure helps to contribute towards supporting ports and terminals key cost drivers due to growing transport of BEV´s.

Keywords: *RoRo ports and terminals, Battery Electric vehicles, financial considerations, Logistic operations, Safety measures, Infrastructure adaptation, Cost drivers*

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List of Abbreviations

RoRo	Roll-on Roll-off
BEV	Battery Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
GHG	Greenhouse Gases
IMDG	Internation Maritime Dangerous Goods
Li-ion	Lithium-ion
NFPA	National Fire Protection Association
FFFS	Fixed Fire Fighting Systems
RES	Renewable Energy Sources
EU	European Union
EVSE	Electric Vehicle Supply Equipment
ISO	International Standard Organization
IEC	International Electrochemical Commission
SAE	Society of Automotive Engineers
HCS	Hollow Core Slabs
OEM	Original Equipment Manufacturer

1. Introduction

1.1 Background

The transportation sector registered 16.2% of global greenhouse emissions in 2016 (Ritchie & Roser, 2020). In terms of CO2 equivalent, the shipping industry contributes 1.7% and the road transportation accounted for 11.9% of the total Green House Gases emission (Ritchie & Roser, 2020). Although within Road transport GHG emissions, the emissions from passenger cars account for 60% of the emission (European Parliment,2022). According to Munzel et al. (2019) Plug in electric vehicles, both Battery Electric Vehicle (BEV) and plug in hybrid vehicles have high potential to reduce global and local emission and contribute to carbon dioxide reduction and clean air targets (Munzel et al.,2019).The introduction of BEVs marks a key transition in automotive or the vehicle industry, that reflects a strong and growing commitment to sustainability, and the reduction of the effects and impacts of climate change (Senyapar et al.,2024). The solutions in vehicle sector are more inclined towards battery electrical vehicles, resulting in surge in demands for transportation and shipping of Battery Electrical Vehicles (BEVs) (European Parliament, 2022).

In the coming decade it is projected to have an increase in demands of BEVs around Europe, because a new Internal combustion engine vehicle will not be able to be registered starting from the year 2035(European Parliment,2022). The global demand for Battery Electric Vehicles (BEVs) has surged remarkably in recent years and has resulted in advancements in battery technology and environmental policies. EVs accounted for 13% of global seaborne car trade in 2023, up from just 3% in 2019 (Ding & Yang,2025). However, According to a report of the International Energy Agency, the increased number of EVs models is an important driving force as well as the decrease in battery price (Vrabie, 2022).According to Bloomberg, ‘in 2030 will be close to half of what they are today, but it may not be smooth sailing to get there’ (Vrabie, 2022).

RoRo ports and terminals are deemed as ‘pure´ when they have vessels that carry cars such as ICEVs & BEV´s, trucks, semi-trailers or platforms and other rolled cargo (Morales-Fusco, 2010). A RoRo port or terminal does not only transport different types of rolling cargo but also complex cargoes like breakbulk which are placed on roll trailer or a pallet and is then rolled on and rolled off on the vessels, such as turbines, yachts and windmill blades (Hansen,2019). At present as a general practice in the industry for loading operations to commence only after the vessel or a deck is fully Discharged (Anastasia, et al., 2019). Generally, the RoRo services are liner services where frequent, scheduled seaborne transport services are covered between predestined ports of call (Anastasia, et al., 2019). RoRo vessels are described as horizontally loading vessels, as their cargo can be carried or towed into the vessel or brought in on wheeled vehicles without any special equipment (Anastasia, et.al, 2019).

The demand for BEVs in Europe indicates increased risks of fires in RoRo shipping of BEVs (González-Almeida et al., 2023). It is due to shipping of BEVs including potential fire risks caused by a Thermal Runaway (TR) of their lithium-ion (Li-ion) batteries (González-Almeida et al., 2023). The likelihood of fire incidents related to shipping of BEVs will therefore increase (Bryant et al., 2022). IMDG Special Provisions 961 and 962 highlights the requirements for vehicles which are being carried on board a transport vessel (International Union of Marine Insurance, 2024).As sea ports and terminals are valuable assets, in the given uncertain and complex environment further refinements are needed to assess risks and prioritize protective measures for these critical areas in the logistics infrastructure (Kambiz et.al, 2011).

To prevent BEV fires, stakeholders involved in RoRo shipping of BEVs should consider preventive measures to avoid risks and hazards while handling BEVs at terminals and vessels (Gao et al., 2022). There is also a need to have standardized operation specifications and processes in handling BEVs (Zang & Gao, 2022). The supporting BEV charging fault diagnosis, safety operation and maintenance service system, and that fault analysis and diagnosis of the charging facilities rely on the knowledge and experience of personnel (Zang & Gao, 2022). Some of the research also addresses that the lithium-ion batteries included in BEVs make them heavier than Internal combustion Engine vehicles (ICEVs) due to this there is a considerable impact on the transport infrastructure (Kumar and Thakur, 2022).Additionally, use of BEVs for charging would require a substantial amount of power from the current existing power grids that could have impact on the presently working distribution system (Mutaraff,2022). Therefore, the implementation of charging stations in ports could lead to an increase in costs of infrastructure (Mutaraff,2022). The published literature provides an overview of rising BEVs, its risks and hazards. Regardless of the published studies on RoRo shipping of BEVs, there is still a gap in academic literature analyzing impact in terms of RoRo ports and terminals. This thesis aims to fill this gap by presenting categories that were identified to assess the costs for RoRo shipping of BEVs. It will also focus on the financial considerations that are needed to the taken by ports and terminals for the shipping of BEV´s.

1.2 Purpose and Research Questions:

The purpose of this thesis is to present a verified model for assessment costs that include safety measures and infrastructure in RoRo shipping of BEVs from a ports and terminals perspective. The aim is to explore costs involved in logistics operations, prevention and detection of BEV fires. Additionally, investigate costs of infrastructure development for ports and terminals. The presented model should be used to support terminal managers in the financial consideration that will help terminals during the shipment of BEV´s.

Based on the stated purpose, the following three RQs have been used:

RQ1: What costs for logistic operations exist in RoRo shipping of BEV´s?

RQ2: What costs of safety measures exist in operational RoRo shipping of BEVs?

RQ3: What costs related to terminal infrastructure development should be considered in RoRo shipping of BEVs?

1.3 Limitations

The limitations of this Master thesis are presented in the paragraphs below.

Considering the geographic location of Chalmers University of Technology, this thesis is only limited to the ports and terminals in Northern Europe. As only a limited number of interviews were conducted for this thesis covering some northern European ports, the validity of this research is not applicable at a global level or on the general scale. It only covers the RoRo terminals which handle only automobiles and therefore does not cover the terminals which handle multiple cargoes.

Due to the broad spectrum in the automobile sectors this thesis limited to only Battery electric vehicles (BEVs). Moreover, it only limits newly manufactured vehicles and does not consider a used vehicle. A fully battery powered electric truck is not considered in the research topic. Additionally, as this topic involves rapidly evolving technology within BEV´s certain findings and references are limited to the current available academic articles and references.

The focus only limits the study and identification of costs for the port and terminals due to BEV´s and not the cost-effective solutions or measures. Additionally, this research is only limited to the direct costs and therefore does not include the indirect or the opportunity costs. It focuses on the operational and infrastructure cost and safety costs but does not capture full life cycle costs which are maintenance, depreciation or replacement costs of the materials under this topic. Furthermore, it is only limited from the BEV entering gates of the load ports until it exits the gates of the discharge ports. Lastly, the study is limited only until spring 2026.

1.4 Thesis outline

The outline of this Thesis is as follows: The reader is introduced in Chapter 1 to the background of the topic and explains why the subject needs to be investigated, which then is followed by research questions and limitations. Then the Frame of references in Chapter 2 provides the readers with a current academic and theoretical framework for the study. It also provides a review of literature under this chapter. The methodology section in Chapter 3 outlines the design, data collection methods, and case study conducted for the chosen topic. Thereafter, in chapter 4 of the Result and analysis sections, the interview results are then connected to the theoretical findings of the relevant research fields. In chapter 5 of the Discussion section, the results are discussed and elaborated. Finally, in Chapter 6, the findings are concluded where the answers to the research questions are provided following the practical implications and suggestions for future research related to the topic of this thesis.

2. Frame of reference

2.1 Logistic operations in RoRo shipping of BEVs

Majority of the Roll-on/ roll-off (RoRo) vessels have one external ramp connected to the main deck because this requires less port infrastructure for servicing vessels (Kaptan, 2022). Cargo meaning the RoRo vehicles need to pass over the external ramp connected with the main deck and is driven to other decks which means the Loading and discharging operations are subject to precedence rules, this is based on safety requirement and the structure of decks through internal ramps of a Roll-on/roll-off vessel (Jia et al. ,2022). The load and discharge operation of the BEVs mainly depend on the drivers, i.e. the stevedores or shore crew (Chen et al., 2025). Puisa (2021) proposed a model to enhance the quality of optimal use of the deck space of Ro-Ro ships. He claimed that if the cargo stowage on the RoRo decks is optimized then that contributes to the increase in stability of the vessel, improves fire safety and cargo handling efficiency.

During the loading and discharging of BEVs, particular care is required to avoid impacts or collisions that could damage the battery (Bao et al., 2023). In principle, the battery should be disconnected once the BEV has been loaded onto the vessel, and the cable should be covered and secured (Bao et al., 2023). Used BEVs should be screened and carefully inspected before being allowed onboard (International Union of Marine Insurance, 2024). If there is any doubt that a BEV battery is damaged or defective, the vehicle should only be accepted if the battery has been removed and no leakage is present (International Union of Marine Insurance, 2024). In addition, extra lashing should be used to prevent movement while the vessel is underway (Bao et al., 2023).

RoRo terminals have a important role in loading and discharge operations of the BEV´s from the RoRo ships. The terminals not only have to invest in physical but also have to carry out stevedore or shore crew training, shop floor reorganization and safety/security adjustment (Fredouet,2024). For vessels arriving at the RoRo port, a load plan is made at the terminal. The load plan indicates the positions of the vehicles on board of the vessels that are to be filled with specific trailers which ensure the ship's stability while it is underway (Jia et.al,2022). RoRo terminals are dependent on human resources because stevedores must handle one vehicle at a time (Park et.al,2022). Therefore, the stevedores are under pressure to complete tasks within the allocated time, that can lead to human errors and safety issues (Park et al., 2022). In a shipping port, where the number of distribution operations is performed, and which consequently lead to big investments and deep technical and organizational adjustment, would want to host potentially growing BEV import/export flows (Fredouet,2024).

However, Wu et al. (2021) mentioned it would better not to permit the BEVs to be charged while being shipped on vessels because the chances of explosion could increase. Therefore, the terminals that are involved in operations of BEV´s will have to invest in the charging facilities (Fredouet,2024). Reduced turnaround times are both critical for ship operators and for terminal operators in terms of cost effectiveness (Jia et al., 2022). This is achieved not only by simplified administrative services, but also by effective preparation and planning for time-efficient discharging and loading operations (Jia et.al,2022).

2.2 Safety Measures costs RoRo Shipping of BEVs

BEV fires may result from thermal runaway triggered by battery defects, charging failures, or mechanical damage following collisions (Brzezinska & Bryant, 2022). Lithium-ion batteries also have a significant risk of reignition after initial extinguishment, complicating fire response efforts (Brzezinska & Bryant, 2022).

The costs of safety measures associated with BEV transport can be categorized into fire prevention, fire detection, and fire suppression systems (Brzezinska & Bryant, 2022). This categorization reflects a widely adopted defense in depth fire-safety framework for lithium-ion battery applications and combining monitoring, thermal management, and firefighting systems is crucially needed for the fire safety (Li et al., 2024). Fire prevention costs relates to measures which focuses at reducing ignition likelihood, including battery condition monitoring, state of charge, and prevention of thermal runaway initiation (Bisschop et al., 2019).Fire detection costs involve the installation of early warning systems designed to identify abnormal heat release or gas emissions during the early stages of lithium-ion battery failure (Qiao et al., 2025).Fire extinguishing costs includes specialized firefighting systems and equipment required to manage lithium-ion battery fires, which demand prolonged cooling and higher source input compared to conventional vehicle fires (Brzezinska & Bryant, 2022).

2.2.1 Fire Prevention

To prevent the battery from exploding, an overpressure release valve is built in which re-leases the gases from the battery, however Li-ion battery mainly starts due to an internal cell short circuit (Sturk & Hoffmann, 2013). Even if there is no immediate fire following a collision, damage to the integrity of the battery pack can result in thermal runaway with later ignition and reignition which has proven difficult to contain (Boehmer et al., 2021). The safety feature of BEVs lack built-in automated suppression systems which make it dependent on the external systems which are mandatory to extinguish fire (Barelli et al., 2021).

Fire prevention is highly dependent on the location in which fire has occurred, which could be in an open or enclosed parking space (Boehmer et al., 2021). Boehmer et al. (2021) also mentions that to maintain structural integrity and minimize the risk of fire spread, open parking structures are generally required to be built using materials classified as non-combustible or limited combustible under standardized testing. Exceptions to this requirement may apply in specific cases, such as when the structure is fitted with automatic sprinkler systems or adheres to prescribed height restrictions. In contrast, enclosed parking structures are typically mandated to include both fire alarms and automatic sprinkler systems (Boehmer et al., 2021). The absence of similar protection requirements for open structures is likely due to practical considerations and their inherent ability to vent hot gases, which slows the progression of fire. Additionally, fires in open structures are more visible and accessible, potentially enabling quicker detection and response by fire services (Boehmer et al., 2021).

The active fire prevention systems are critical in mitigating fire risks on RoRo vessels (Troitzsch, 2016). Battery casings often hinder water penetration, making suppression effective only after the fire spreads to the car's body. Fire tests indicate that water is highly effective for cooling, but large volumes—up to 10 m^3—are required for complete extinguishment (Barelli et al., 2021). Fire crews are required to apply water to the exterior of the battery pack for hours, while continuously monitoring the temperature (Boehmer et al., 2021). Oxygen reduction

systems can create low-oxygen environments to prevent fire spread while allowing BEV charging (Barelli et al., 2021).

Another important fire preventive measure which can be proactively taken is by increasing the spacing between electric vehicles (Boehmer et al.,2021). For example, Fire tests were carried out with vehicle spacing between 0.4 and 0.8 m (1.3 to 2.6 ft) and the results showed that the ignition of a second vehicle occurred within 5 to 28 minutes after the first vehicle ignited which was due to radiative heating of rubber components on the adjacent vehicle (Boehmer et al., 2021). Boehmer et al. (2021) report that, in enclosed parking spaces, flames from an electric vehicle fire can ignite an immediately adjacent vehicle. Consequently, appropriate vehicle spacing emerges as an essential measure for reducing fire spread and enhancing fire prevention and protection (Boehmer et al., 2021).

Fire prevention costs can be assessed at micro and macro levels. Micro-level costs include installation and maintenance of active and passive systems, while macro-level costs aggregate these across regions or sectors (Unobe et al., 2024). Active measures, such as sprinklers and detection systems, are activated during fire events, whereas passive measures aim to prevent fire spread without activation (Unobe et al., 2024). Cost reduction strategies in RoRo terminals, including improved workforce utilization and facility upgrades, are essential for operational efficiency (Park et al., 2023)

2.2.2 Fire Detection systems

Early smoke detection within the “golden minutes” is crucial for minimising casualties and property damage (Zuo et al., 2024). Fire detection systems greatly employ optical technologies, influencing computer vision for flame and smoke recognition, giving wide coverage and real-time visualization (Yang et al., 2024). The detection that happens with Image-based is less affected by environmental changes compared to traditional sensors (Zuo et al., 2024). Digital cameras modified to record near infrared (NIR) are one of the best options for fire detection and monitoring and are much more affordable (<$500) (Burnett & Wing, 2018). The detection systems may depend on the location or area. As an example, NFPA 502 directive instructs at least two independent detection methods in tunnels, typically combining heat and smoke detection (Hynynen et al., 2023). Swedish building codes also link permissible area size to the presence of detection and suppression systems (Hynynen et al., 2023).

2.2.3 Fire Extinguishing systems and equipment

Experiments show that fixed sprinkler systems can control large-scale Li-ion battery fires (Boehmer et al., 2021). The few tests which involve the full-scale vehicle fires under overhead sprinkler systems in a standard garage setting indicate that these sprinklers are effective in extinguishing the fire (Boehmer et al., 2021). Additionally, Zhao et al. (2024) mentions electric vehicle fires can generally be extinguished through the application of large, sustained volumes of water, as recommended by the NFPA Electric Vehicle Emergency Field Guide, although such water supply is typically only achievable once professional fire services arrive. International standards increasingly mandate water-based fire extinguishing systems. For instance, tunnels in Australia, New Zealand, and Japan require fixed firefighting systems (FFFS) with water application rates of 6.5–10 mm/min (Hynynen et al., 2023). Similarly, National Fire PA. 88A (2023) and IBC (2021) require sprinklers in large parking structures, while Dutch regulations mandate sprinklers in garages over 1,000 m² due to increased fire loads from modern vehicles (Hynynen et al., 2023). Studies confirm that sprinkler systems can prevent fire spread between vehicles, including BEVs (Hynynen et al., 2023). Onboard vessels, SOLAS Chapter II-2

prescribes fixed fire detection and suppression systems (IMO, 2002; The Standard Club Ltd, 2021). High-pressure water mist systems have proven effective in reducing temperatures and limiting fire spread (Magdolenová, 2021). If these water-based sprinklers cannot be used for extinguishing but they can be helpful as a fire containment system with sufficient water supply, which should allow firefighting personnel to arrive and extinguish the fire (Boehmer et al., 2021).However, contact with salt water introduces additional hazards, as the high conductivity of saline solutions can cause rapid battery discharge, internal corrosion, and electrolyte degradation, while generating chemically contaminated water containing metals and toxic compounds (Zhao et al., 2024; Bordes et al., 2024; Torabian et al., 2022).

Moreover, Liquid nitrogen has emerged as an effective extinguishing agent due to its cooling properties and non-toxic nature, though storage and transport remain challenges (Zhang et al., 2022). Additionally, Dry chemical agents and carbon dioxide are commonly referenced as fire-fighting options for battery fires due to their reduced electrocution risk, although their effectiveness is limited when addressing lithium-ion battery thermal runaway (Zhao et al., 2024).

There are many fire extinguishing equipment's such as fire blankets that are identified as an effective early-stage fire control measure, capable of extinguishing visible flames and preventing fire spread to surrounding vehicles, although they do not terminate battery thermal runaway and re-ignition may occur once the blanket is removed (Zhao et al., 2024).

2.2.4 Insurance costs

Insurance costs for battery electric vehicle (BEV) transport reflect the heightened fire risk associated with lithium-ion batteries and the potential for severe damage in maritime environments (Unobe et al., 2024). As a result, insurance premiums for vessels carrying BEVs are influenced not only by incident probability but also by the complexity and scale of potential fire related damage (Unobe et al., 2024).

Marine insurance risk assessment in maritime transport is strongly influenced by compliance with international safety regulations, as adherence to established fire safety and emergency response requirements reduces insurers' exposure to catastrophic losses (Jahanian, 2022). Regulatory compliance therefore functions as a risk-mitigation signal in underwriting processes, where vessels demonstrating conformity with safety standards are perceived as lower insurance risks (Jahanian, 2022). In parallel, the presence of advanced fire detection systems and effective firefighting arrangements has been shown to reduce expected loss severity in maritime fire scenarios involving hazardous cargoes such as lithium-ion batteries (Qiao et al., 2025). Conversely, limitations in onboard fire suppression effectiveness and uncertainty surrounding fire containment increase potential damage escalation, which is reflected in more conservative insurance terms and higher premium levels (Qiao et al., 2025).

2.2.5 Safety training

Safety training is essential for ensuring crew familiarization with firefighting tools, as regular firefighting exercises have been shown to significantly improve firefighting competency and effective equipment usage (Sima et al., 2019). In addition, structured fire-fighting drills contribute to improved coordination and communication among crew members, reducing response time and operational errors during fire incidents (Ramohale et al., 2025).

Repeated practical training enhances procedural knowledge, situational awareness, and confidence in the use of firefighting systems which are critical factors during emergency response situations (Sima et al., 2019). Continuous training and regular refresher exercises have also been associated with improved compliance with safety procedures and more effective deployment of fire-fighting equipment under realistic emergency conditions (Ramohale et al., 2025).

2.3 Infrastructure cost at RoRo port terminals in shipping of BEVs

The early movers in this industry have started making technical investments and organizational redesigns that are deemed needed for the management of BEV flows (Fredouet,2024). Infrastructure costs compromise the cost of charging stations and the development costs of parking spaces for BEV´s.

2.3.1 Charging stations

The rising number of battery electric vehicles (BEVs) and its need for electrical power can lead to bottlenecks in the electricity grid infrastructure if it is not strengthened (Straub et al., 2021). The terminals will need to invest in charging infrastructures to become pioneers for growing BEV industry (Fredouet,2024). The BEV charging station would have considerable sized loads that will be applied in areas that earlier had only light electrical loads. A parking bay might require some minimal power for lighting purposes and the power density of these loads averaged over the surface area of the parking spaces is very little, therefore, increased power load and electricity cost should be considered in investments (Fox et al.,2011). If all private automobiles become electric then energy consumption will rise to such a level that is impossible to be satisfied by the energy producing companies (Vrabie,2022). Building a charging station where the charging stations are far from the grid or the current existing grid is weaker, laying new transmission lines might be an expensive solution. To overcome such challenge, mobile charging stations can be built using Renewable Energy Source (RES) i.e. Wind, fuel cell etc. and static battery packs can be one of the solutions (Umair et al., 2022). If the locations of the activities or charging infrastructures are known, the spatial and temporal distribution of the energy and power demand for that area can be calculated from the mobility profiles by applying charging strategies (Straub et al., 2021).

The set up of charging stations in remote or isolated areas poses huge complications due to the substantial investment required to connect to the main grid (Umair et. al, 2022). The prime challenge that could occur while installation of charging infrastructure in remote areas where access to the main grid requires a heavy amount of investment. Therefore, rather than laying and investing in lengthy underground or overhead transmission lines (Umair et al., 2022). The standalone/mobile charging stations are suggested which are formed by integrating Renewable Energy Sources (RES) along with stationary battery packs. This approach gives a more workable solution compared to extensive underground or overhead transmission lines (Umair et al., 2022).Total net electricity generation in the EU was 2,780,000 GWh in 2019 and 3,785,973 GWh in 2021.Therefore, the rise in annual electricity demand would be approximately 24.16% if taken into account the year 2019 (or 17.74% if we consider year 2021 as a reference) (Vrabie,2022). The grids that are incorporated with a substantial amount of Renewable Energy Sources (RES) and BEVs, which are very uncertain and intermittent in nature. To cope with this challenge, massive stationary battery packs can be installed; however, this is a less cost-effective solution (Umair et. Al, 2022). The Charging infrastructure for BEVs

needs to fulfill the EU Directive 2014/35/EU, which is called Low Voltage Directive (LVD). The LVD requires that the charging station needs to be safe against electric shock and fire. In the LVD, it is up to the producer of the charging infrastructure to certify that the product meets these requirements. Generally, there is no specific requirement that needs to be fulfilled, but for many products the producers of the BEV charging stations tend to reach some consensus about what needs to be fulfilled in form of certain standards etc. (Hynynen et al., 2023).If the need for a charging station is one directional, un-controlled rectification based on H-bridge diodes is preferred as it is considered quite simpler and a cost-effective way (Umair et al., 2022).In most of the locations, the route of cables connecting the Electric Vehicle Supply Equipment (EVSE) to the vehicle should not block or hinder pathway subject to heavy foot traffic. Proper cable management is necessary to avoid trip risks and ensure safety in areas with high pedestrian activity (Fox et al., 2011).

The developed BEV charging station and infrastructure must integrate with industry standards, available technology along with governmental policies (Khalid et al.,2021). Many international standards have been created to harmonize EV charging patterns and ensure universal acceptance (Rajendran et al., 2021). International standards are created and established by a team of experts and are adopted universally (Khalid et.al,2021). For deployment of EV charging stations successfully, there are various international standards that are developed and published (Khalid et al.,2021). The combination of IEC (International Electrochemical Commission) and ISO (International Standard Organisation) have established standards for vehicle–to–grid communication interface systems for BEVs. While on the other hand, SAE (Society of Automotive Engineers) have provided international standards for wireless charging communication (Rajendran et al., 2021). There is a lack of founded, firm and developed standards specifically in DC connected charging stations (Khalid et.al,2021). Therefore, new extensive and thorough concepts and standards are needed to make new technologies like the BEV charging stations a success (Schnee et al., 2020).

2.3.2 Parking spaces

Battery Electric Vehicle (BEV) fires have recently appeared as a huge safety concern in this society, especially when occured in car parking spaces, where the damage done by it can be severe. The fatalities and injuries that are reported and the associated economic losses are substantial (Kang et al.,2025).

Despite growing popularity in the current world, the concerns about the risk of BEV fires, particularly in urban cities like underground car parks and multi-storage parking infrastructures, have increased recently (Kang et al.,2025). Considering the difference between hazards of Internal Combustion Engine Vehicles (ICEV) and Battery Electric Vehicle (BEV) fire, it is crucial to reassess the fire protection codes and firefighting strategies for modern BEV fires in underground car parks (Kang et.al,2025). The maximum temperature of the BEV fire is higher than that of the ICEV. This shows that the high temperature can affect the structural performance degradation of reinforced concrete of parking space (Heo et.al, 2025). Additionally, a vehicle fire which burns more vigorously and fast could produce a massive threat to nearby objects, including nearby cars, structural members (such as columns, slabs, beams and walls), and BEV charging stations (Kang et al.,2025).

Hollow-core slabs (HCSs) are mainly used in the floor systems of parking structures. HCS is a specimen precast slab that can maximize the reduction of concrete volume because voids exist in the cross-section and help simplify transportation and lifting operations on-site owing to self-

weight reduction (Heo,2024). It is argued that if a BEV fire takes place, the performance of the reinforcement and concrete of the HCS member will decrease. Hence, in the design of HCS structures with BEV arrangements, the consideration of application of additional fire resistance methods should be considered to further improve fire resistance performance (Heo,2024). Additionally, weights of BEVs have increased over the years (Kemper et al., 2022), they generally have higher weight than traditional Internal combustion vehicles (Sandrini et al., 2025). Batteries play a major part for BEVs that constitute a major portion of vehicles' weight (Akbar, 2020). The idea of Live loads measure for multi-storey car parking garages and car parks could be considered safe for not only present vehicles but also future vehicles as the overall weights of cars can most likely increase (Kemper et al.,2022).This indicates there is a need to determine the impact costs due to increased weight for BEVs for ports and terminals.

3. Methodology

This chapter gives research design and methodology adopted to address the research purpose and questions of this thesis. A qualitative-dominant mixed-methods approach refers to a research design in which qualitative data constitute the primary source of analysis, while quantitative data are used in a complementary role to contextualize and support qualitative findings (Creswell & Plano Clark, 2018, Hesse-Biber et al., 2015). This research adopts a mixed methods approach, integrating qualitative and quantitative techniques within a single study (Creswell, 2014), with a primary emphasis on qualitative data through a structured literature review and a case study based on semi structured interviews. This approach allows for a systematic exploration of the financial implications related to logistics operations, safety measures, and infrastructure development with regards to BEVs.

3.1 Research Approach

The study adopts an abductive research approach, which is suitable for research that moves back and forth between theory and observed data, and it involves continuously comparing empirical observations with existing theories, allowing researchers to enhance theoretical understanding while interpreting empirical findings (Kovács & Spens, 2005). Abductive reasoning supports a continuous exchange between empirical findings and theoretical perspectives, enabling theory of development to remain closely grounded in observed practice (Kovács & Spens, 2005). This is particularly relevant in logistics research, where complex operations, multiple different stakeholders, and changing rules and technologies come together. In the recent logistics studies focuses on the upcoming phenomena such as sustainability transitions, new technologies, and safety-critical operations which require flexible research designs that unit theory with practice rather than treating them as separate stages (Grant et al., 2023). By combining established logistics and safety literature with real observational data from interviews, an abductive approach helps understand the situation in its context while building theory based on real world practice. (Kovács & Spens, 2005; Grant et al., 2023). The abductive research was applied on a repetitive basis between literature and empirical data, in which an initial theme or concept was taken from literature which was taken for analysis and continually refined based on the ideas obtained by interviews.

3.2 Literature Review

The literature review forms the theoretical foundation of the thesis by recognizing key concepts, theories, and research gaps that steers the study design and analysis (Luft et al., 2022), giving a clear overview of what is already known, the main ideas behind and the gaps in research about transportation BEVs. A rigorous literature review is essential for developing a coherent theoretical framework and for positioning the study within the existing body of academic research (Webster & Watson, 2002).

Given the research topic crosses several academic fields which include financial consideration of logistics operations, fire safety engineering, and infrastructure development, a structured and transparent literature review approach was adopted (Webster and Watson, 2002). As recommended by Webster and Watson (2002), the review focused on identifying high-quality, peer-reviewed publications that contribute to theory development, while also considering relevant practical findings and industry focused research. Due to the novelty and rapidly evolving nature of BEV logistics and safety considerations, conference papers and selected grey literature were also read and included when they were reliable, relevant, and useful for the study.

3.2.1 Scope and Focus of the review

The literature review was designed to address three main thematic areas that are directly aligned with the research purpose and the three research questions. Defining the scope of the review through key thematic focus areas is a commonly adopted approach in systematic and semi-systematic literature reviews because it keeps the review to remain focused while capturing key dimensions of the research problem (Tranfield et al., 2003).

The three themes, that are Logistics operations, safety measures and infrastructure requirements were first identified by reading the literature and then they were gradually refined as the review progressed. Linking these themes together captures the critical operational and financial factors that affect shipping transportation of BEV. By building up the literature review around these themes, the thesis establishes a clear theoretical basis that supports both safety related costs and infrastructure development costs (Luft et al., 2022).

3.2.2 Search Strategy and Databases

A systematic literature search was conducted using predefined keywords and structured search queries across relevant academic databases (Bramer et al., 2018). The search process was documented to ensure transparency and allow the literature review to be assessed and compared. Systematic literature reviews require clear and consistent search strategies to minimize bias and ensure the reliability of findings (Brignardello-Petersen et al., 2024).

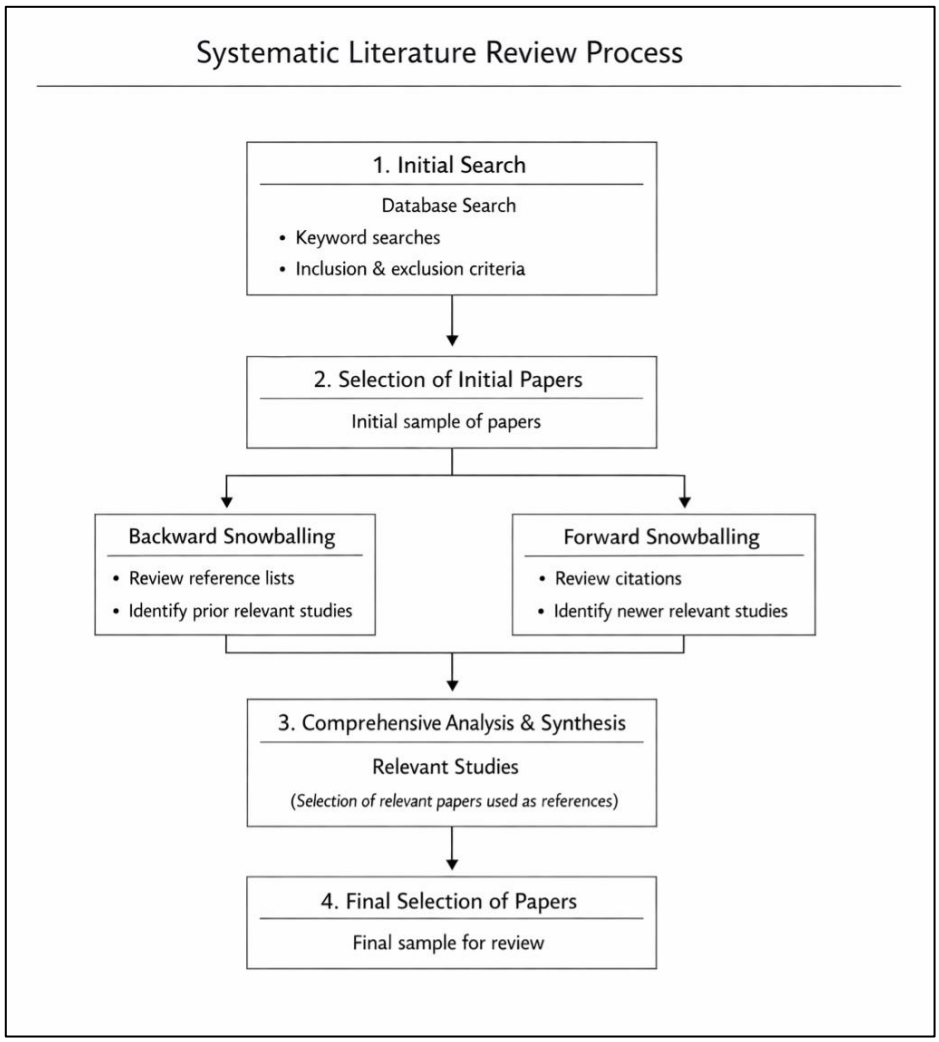


Figure 1. Systematic literature review process illustrating the initial database search, selection of initial papers through backward and forward snowballing, comprehensive analysis and synthesis of relevant studies, and final selection of papers for review (adapted from Webster & Watson, 2002; Tranfield et al., 2003; Wohlin, 2014).

1.Initial search

Scopus, Web of Science, and ScienceDirect were selected as databases for the initial search (step 1), since these provides broad coverage of high-quality, peer-reviewed journals across multiple relevant fields of studies which include logistics, maritime operations, financial studies and safety research. The Web of Science database was used to find frequently cited studies, and ScienceDirect was helpful in accessing technical and engineering research.

In addition to database searches, specific inclusion and exclusion criteria were formulated to evaluate the relevance and quality of literature. The following criteria were applied as follows:

- Year Range: 2015 to 2026. From the year 2015 an increasing trend of BEV sales was observed and also there was a growth in published articles with regards to BEV in search engines i.e. Web of science, Scopus etc, which created a base to use year range from 2015 to 2026.
- Document type: Article, conference paper, book etc. As the thesis is based on relatively new and niche topics, there were plenty of non-academic or grey literature sources found on this subject which were unreliable, lacked quality content and biased information.

Therefore, only peer-reviewed scientific articles were used in the literature review to ensure the quality and reliability of the reviewed evidence which is in line with established systematic literature review principles (Tranfield et al., 2003).

- Headline matched the purpose of the study
- Language: English

2.Selection of Initial papers

To select relevant papers to this study, both backward and forward snowballing techniques according to Wohlin et al., (2014) was applied (step 2). Backward snowballing involved evaluating the reference lists of main articles, while forward snowballing focused on identifying more recent studies. This combined approach amplifies the coverage and reduces the risk of omitting important studies which particularly are in emerging research areas. In addition to journal articles, the technical reports, and industry guidelines were included when they provided valuable insights into BEV fire safety, terminal infrastructure, financial concepts, or operations. This decision has a greater importance of incorporating high-quality grey literature when researching novel or practice-driven topics (Webster & Watson, 2002).

3.Comprehensive analysis & synthesis

After shortlisting the initial papers, full text is systematically reviewed to understand its relevance, quality, and if any contribution can be made toward the research topic. The papers were extensively reviewed with respect to their research objectives and key findings or theoretical perspectives which lead to exclusion of irrelevant and out-of-scope papers. The remaining studies are then grouped and compared to identify common themes and patterns. The purpose of this step is not to summarize individual studies but also to integrate the existing knowledge and understanding of the research area, resulting in a more polished set of relevant studies that gives a foundation of the literature review (Webster & Watson, 2002).

4.Final selection of papers

The final selection represents the last filtering process that gives a conclusive set of papers to be included in the literature review. Final set of high-quality and papers that are directly relevant to the research questions are chosen and finalized. This final set of papers constitutes the core evidence base for the literature review, analysis, and discussion, ensuring transparency, methodological rigor, and replicability of the review process (Tranfield et al., 2003).

The identified and selected papers in each step are presented in table 1

Table 1: Initial literature search

Step 1 (Initial search)				Step 2 and 3 (Snowball backward & forward)	Step 4 Selection of Final Sample
Search strings	**Search field**	**Literature Search result**	**Headline read**	**Abstract screening**	**Full paper read**
"Battery Electric Vehicles" AND "RORO shipping"	Title, abstract, keywords	12,548	30	6	3
"EVs" AND "RORO port terminals"	Title, abstract, keywords	8379	30	5	2
"EV fire"AND "ROROport operation"	Title, abstract, keywords	231	10	4	2
"Fire detection" AND "RORO terminals"	Title, abstract, keywords	82	12	6	2
"Fire and safety' AND 'shipping'	Title, abstract, keywords	208	20	7	4
"EV charging infrastructure" AND terminals	Title, abstract, keywords	3798	24	7	3
"shipping insurance" AND electrified vehicles	Title, abstract, keywords	688	10	5	3
"EV logistics costs" AND "electric vehicles" AND terminals	Title, abstract, keywords	407	12	9	2
Total number of selected papers		26,341	148	49	**21**

The structured literature review built a theoretical foundation for empirical analysis. It highlights the growing complexity of BEV transportation in RoRo logistics which identifies safety measures and infrastructure development as main cost drivers and reveals a lack of integrated cost-focused studies from a port or terminal perspective. These insights were used to develop the research framework. They shaped the structure of the case study and guided the design of the interview protocol.

3.2 Case study

The case study comprises of a in-depth inquiry into a specific and complex phenomenon (i.e., a ‘case’), set within its real-world context (Yin, 2013).

3.2.1 Case Study design and context

The empirical data collected for this study is to determine the additional cost incurred by the terminals for RoRo shipping of BEV´s, from the time BEV enters the terminal until it is loaded onboard vessel and from the time it is discharged from the vessel until its exits the terminal gates.

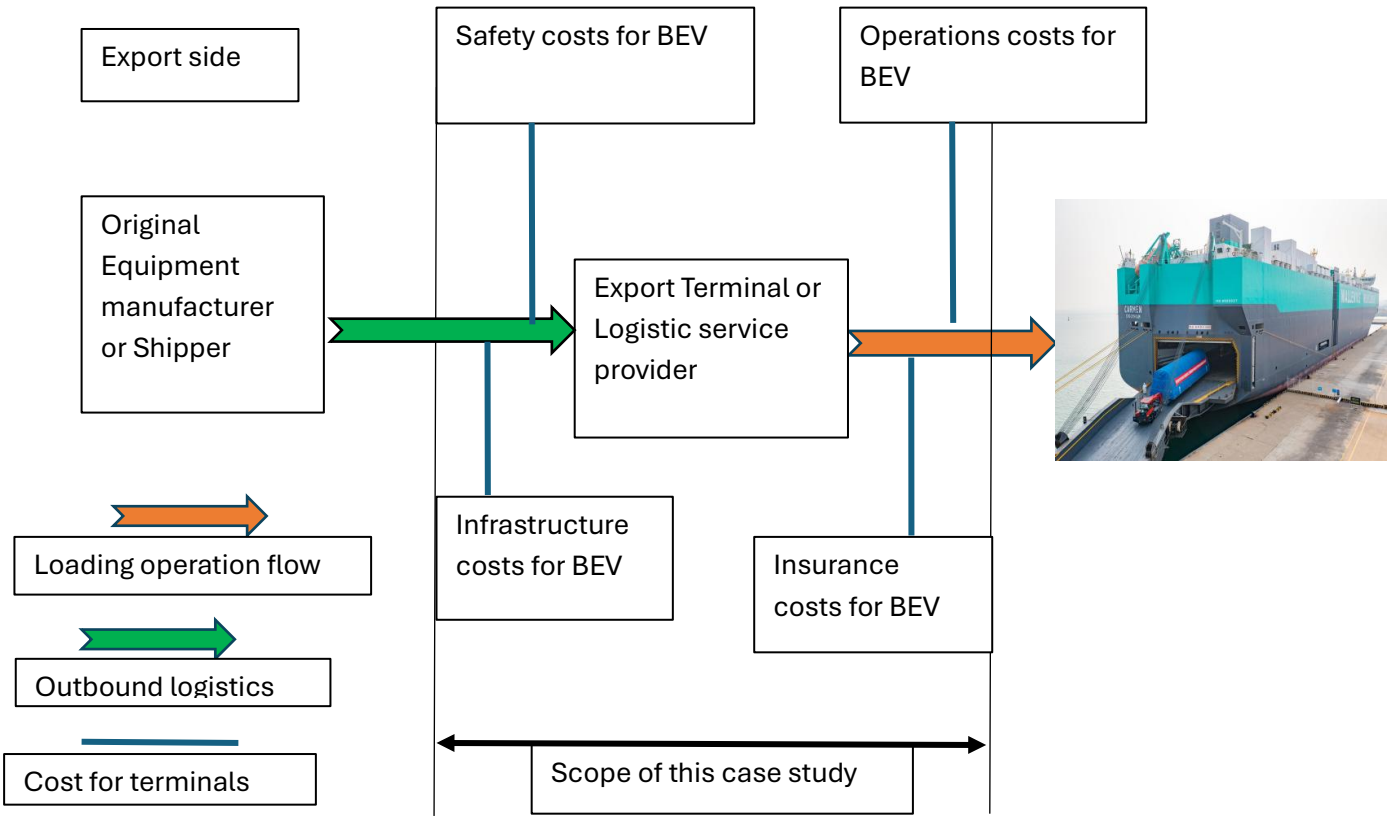
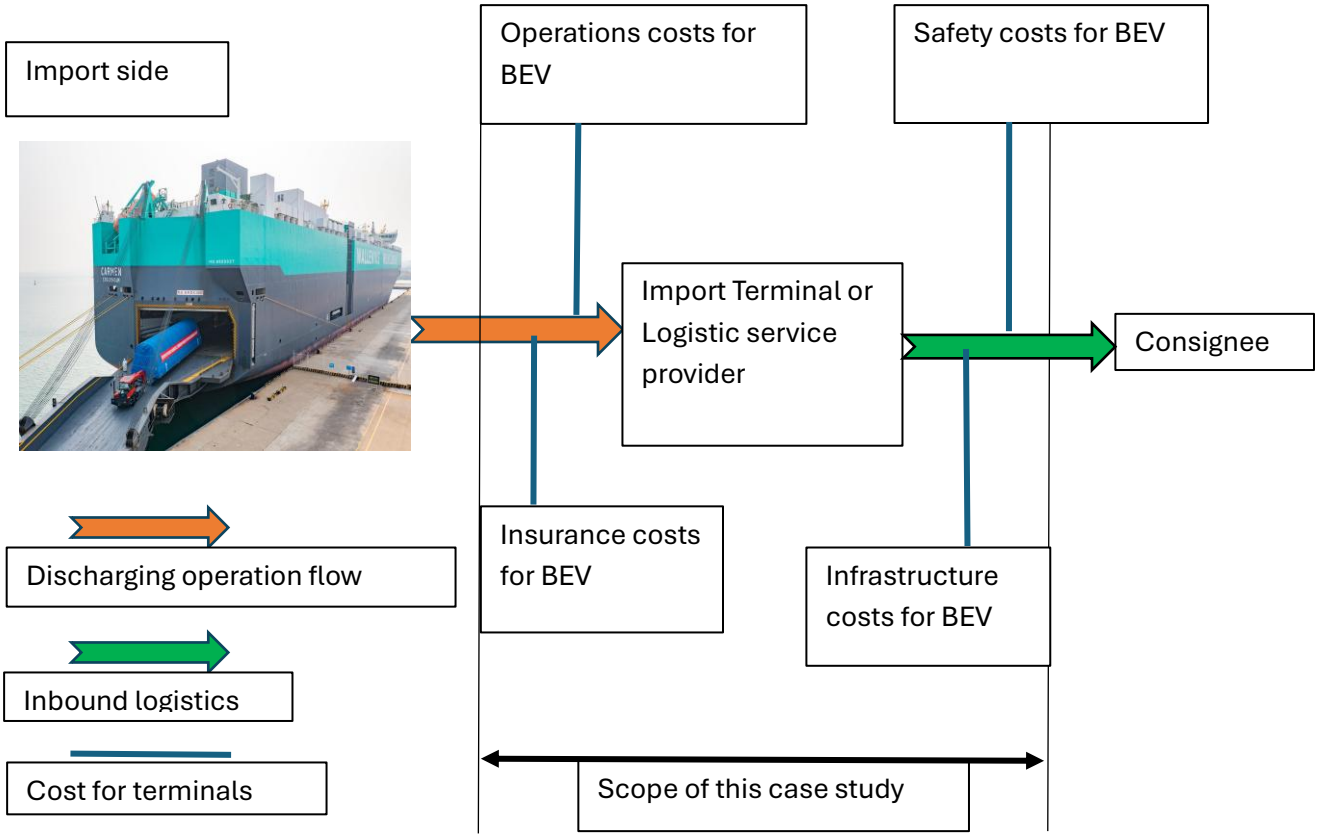


Figure: Representation of Transport / Supply Chain of a BEV´s



There are three main additional costs identified in Figure: Representation of Transport / Supply chain of BEV´s) and literature review, that consists of Logistic operations costs, infrastructure costs and safety costs for RoRo shipping of BEV´s. The scope of this case study accounts for costs consideration for shipping of BEV after Manufacturer of BEV or shipper delivers it to the port/terminal until it is loaded onto the RoRo vessel and after the BEV´s have been discharged from RoRo vessel until the it is out to the consignee. This case also studies the insurance costs for shipping of BEV´s.

3.2.2 Case data collection

The data was collected through semi-structed interviews as suggested by (Yin, 2009). Semi-structured interviews were selected since they proved to be versatile and flexible (Kallio et al., 2016). Semi structured interviews enable mutuality between the interviewer and the interviewee, it also enables interviewer to improvise the follow up questions based on interviewees' response which allows interviewees individual expression (Kallio et al.,2016). In total 6 interviews were conducted (Table 2)

Table 2: Stakeholders involved in the study

Interview number	Date	Person (anonymized)	Company (anonymized)	Position in the company	Years of experience
1	19.09.2025	Interviewee A1	RoRo terminal A1	Digital Development Manager	3
2	26.09.2025	Interviewee A2	RoRo terminal A2	Business area manager	7
3	19.09.2025	Interviewee A3	RoRo terminal A3	General Manager	3
4	19.12.2025	Interviewee B1	RoRo Shipping line B1	Fleet director	3
5	19.09.2025	Interviewee B2	RoRo Shipping line B2	Project Manager	6
6	16.01.2026	Interviewee C1 Interviewee C2 Interviewee C3	Insurance consultant company C1	Specialist Broker Marine Cargo – C1&C2 Junior Broker Marine Cargo - C3	2-7

The semi structured interviews required a certain level of study in the research topic area (Kallio et al., 2016), therefore all the interviewees were selected as the interview questions were based on the knowledge and experience. All the interviews were conducted on Microsoft Teams, which lasted between 30 to 45 minutes. Interviewees were asked in total 9 questions. At the beginning of the interviews were asked about their age, gender, education, position in the company and years' experience.6 of the interviewees were men and 2 were women. The interviews were recorded and transcribed via Microsoft teams. The Transcription is a process of converting audio, video or notes into a written format for qualitative data analysis (Eftekhari,2024). The summary of the transcribed interviews was made by using the Co-pilot function of Microsoft teams for concrete and clear understanding. In order to avoid loss of interpretations, the interview transcripts were also referred to for detailed purposes.

3.2.3 Data analysis

The analysis of transcribed interviews in this study was conducted with a thematic analysis and based on the units of analysis identified in the literature review (Table 3). A thematic analysis is a research method that is used to detect and interpret themes in a data set that mostly lead to new insight or understanding (Naeem et.al,2023).In this analysis the elements were identified and linked to a stream that has a clear and relevant expository flow for the readers (Watson & Webster,2022).

Based on analyzed papers included in the literature review, units of analysis (Table 3) were identified in and chosen to systematically capture the financial dimensions related to the transportation chain of the BEVs. These were grouped into categories to represent the significant cost drivers and operational factors influencing logistics and risk management within our given limit:

Logistics operations in shipping of BEVs include additional costs related to handling procedures, loading/discharging on and off the vessels, training requirements and organizational adjustments linked to BEVs. It covers the theme of operations of RoRo shipping of BEV´s relating to the supplementary expenses for the terminals. This cost driver attends RQ1 which includes associated costs for port and terminals.

Safety measures in RoRo shipping of BEV´s comprises of the costs relating to fire risk mitigation for ports and terminals, which directly addresses RQ2. This theme highlights the costs associated with fire prevention, detection, and extinguishing systems. Additionally, it also includes safety training and insurance related matters in the unit analysis of costs. The reviewed literature focuses on additional safety requirements and financial implications for terminal operations.

Infrastructure at RoRo port and terminal includes in and associated costs at port terminals, which are attended to RQ 3. This theme explores the investments related to charging infrastructure, parking and storage facilities, power supply, and structural modifications required to accommodate logistics of BEVs. The literature reviewed under this theme provides insight into long term capital expenses and continuous infrastructure related costs that ports and terminals must consider as BEV volumes increases which is certain as per the current rising trend.

Table 3: Cost Categories and Unit of analysis for BEV transportation in RoRo Shipping

Cost categories	**Unit of analysis Costs**	**Reference**
Logistics operations in shipping of BEVs	Loading/ Discharging	Bao et al.,2023
	Organizational adjustments	Bao et al.,2023
		International Union of Marine Insurance, 2024
		Fredouet,2024
Safety Measures in RoRo Shipping of BEVs	Active and passive fire prevention systems	Unobe et al., 2024
	Fire Detection systems	Zuo et al 2024
	Fixed fire Extinguishing sprinkler systems	Boehmer et al., 2021
	Safety training	Ramohale et al., 2025
	Insurance premiums	Unobe et al., 2024
Infrastructure cost at RoRo port terminals	Charging stations	Umair et. al, 2022
	Parking space	Heo,2024

Table 3 summarizes key cost categories and associated cost drivers in BEV transportation via RoRo shipping, supported by relevant literature, highlighting the main operational, safety, and infrastructure cost drivers. The unit of analysis denotes the specific cost components within each category, representing the key cost factors identified in the literature.

4. Results and Analysis

This chapter represents the analyzed results of literature review and interviews that were conducted for this thesis in relation to literature presented in chapter 3. The section is divided into three sections based on the three units of analysis of cost categories.

4.1 Logistics operations in shipping of BEV

The analyzed results from literature review and the interviews presented the operational costs that terminals would face that are involved in shipping BEV. This covers costs Loading and discharge, technical and training costs.

There was common feedback noticed in all the interviews mentioning there was NO noticeable additional cost involved when it came to the loading and discharging operation of the BEVs. Therefore, the response regarding terminal handling, i.e. loading or discharging of the BEVs, was done in the same manner as the normal ICEVs. There is no particular difference in driving speeds on board vessels or within the terminal. Thus, interview responses do not go along with published research, when it comes to handling BEVs, and that special attention should be given to avoid collision or damage to batteries that could have financial implications. Apparently, this feedback was addressed by both the port and terminal operator respondents (interviewee A2, Interviewee A3). For example, interviewee A2 mentioned: ***"no special handling for BEV. The same speed and most of the cars have a speed limit".***

In regards of the organizational changes, it was observed out of all six interviews only two interviewee A2 and A3 i.e the terminal operators mentioned of added a new technician role in their organization since the rise of transportation of BEV´s which in turn be considered as increased costs. These were the specialized technicians trained to handle electrical and safety aspects of BEV´s batteries. In addition, their role is also carrying out pre-delivery inspections of imported BEV´s. There were no specific inspections for the export BEV mentioned in any of the interviews. Hence, the interview results go along with the published literature research which asserts ports will need to make deep technical organizational changes when it hosts potential growth of BEV´s.

However, results from two interviews (Interviewee B1 and Interviewee A3) mentioned about having trainings relating to BEV´s. Interviewee B1 from a ferry, Ro-pax and terminal operators confirmed that ship crews have completed "**additional training on all vessels**," that new BEV related equipment has been issued. While Interviewee A3 mentioned shore crew/stevedores receive EV safety training courses costing £300-£400 per person per course. Additionally, mentioning courses were not mandatory but recommended. The other two terminal operators (Interviewee A1 and interviewee A2) mentioned there was no separate training programme for stevedores when it came to EV safety. Hence, this is relevant and confirmed in published literature (Chapter 2.1). Only the interviewee A3 response goes along with it, the other terminal operator responses do not go along with it.

There is a direct relation between the logistics operations and the safety measure for shipping of BEV´s. As both the features are involved in the day-to-day activities for RoRo shipping of BEV´s these form the main costs drives for ports and terminals.

4.2 Safety Measures in RoRo Shipping of BEVs

The results of the conducted literature review show that the cost of safety measures plays a pivotal financial role in RoRo shipping of BEVs. The reviewed literature highlights BEV related hazards as a set of requirements that must be incorporated into safety management systems, with associated costs classified at both macro and microlevels. These costs include active and passive fire prevention systems, Spacing between BEVs, fire extinguishing systems, fire detection, and insurance premiums in shipping of BEV´s.

Active and passive fire prevention systems

The interview results consistently highlight that human safety is the primary concern, while BEV fires are considered high risk due to their unpredictable nature and prolonged duration. This understanding aligns with current literature, which highlights the extended cooling time and complexity associated with BEV fire incidents.

From a theoretical perspective, literature review chapter 2.2.1 addresses fire prevention costs primarily rely on passive measures such as vehicle location (open versus enclosed spaces) and the implementation of passive and active safety systems. These include early detection systems and enhanced ventilation arrangements, which are identified as critical for mitigating fire development and ensuring safe conditions during BEV fire incidents.

Three out of six interview results show a proactive preventive measure such as crew patrol, infrared sensors with add-on fire protection measures such as setting dry risers, and supplementary firefighting infrastructure. For instance, interviewee A3 described thermal screening in a structured way: *"**You can do adhoc check… with an infrared sensor… before a battery has any issues it heats up dramatically**. **We get our security guards to just to scan the decks and if any abnormality appears the technician will go check the car, if safe to do so, move it to the isolation area and monitor it**."* Furthermore, interviewee A3 also reveals that multistorey terminal structures that present greater safety risks for BEV fires, due to limited vertical fire separation and the potential for heat and fire spread that can affect multiple decks simultaneously. These comments from the interviewee A3 suggest that in reality fire prevention of BEV remains manual and if there is a suspension of BEV getting heated up it's tested with infrared sensor and taken to isolation to prevent the spread in case of fire. In such environments, alternative firefighting solutions such as dry risers were highlighted as essential for effective fire suppression.

This comparison suggests that literature primarily focuses on system-based and structural fire prevention measures while industry practice places greater emphasis on operational and traditional human-oriented approaches. From a cost standpoint, this indicates that some lower cost, flexible preventive strategies (e.g. patrols and thermal scanning) may partly substitute more infrastructure-intensive investments, although it may not fully replace them.

The results further show the difference between theoretical recommendations and practical constraints regarding vehicle spacing as a fire prevention measure. The literature identifies increased vehicle spacing as a cost-effective passive fire prevention strategy, particularly for limiting fire propagation in both terminal areas and onboard vessels. It gives this simple measure that can be implemented without significant infrastructure investment and still improving safety outcomes.

However, the interviews findings suggest that increasing vehicles spacing for BEV´s brings operational and economic challenges on practical basis. The terminal operators emphasized that

terminal space is a critical and business sensitive resource. Making increased spacing of vehicles makes it an unfeasible option. As interviewee A1 stated: ***"Electrical cars put into lanes just like normal combustion engine vehicles basically because our hard currency terminal is space, right? The more we can´t afford to waste space and for EVs to be like safely handled."***

Similarly, Interviewee B1 highlighted that onboard operations are greatly affected by spacing requirements because segregation of BEVs can reduce cargo capacity by up to 50%. This shows a direct exchange between fire safety measures and operational efficiency with implications on revenue and transportation costs.

An alternative practical adaptation was suggested by two out of six interviewees that proposed designated parking areas for BEVs as a more feasible and cost-efficient solution compared to full-scale spacing measures. This denotes and in practical terms there is a preference for targeted or small-scale changes rather than system-wide adjustments.

Overall, while the literature presents spacing as an effective and relatively low-cost fire prevention measure, industry practice reveals significant economic and operational barriers to its implementation. This highlights a key gap between theoretical safety optimization and real-world feasibility, where cost implications are driven not only by safety investments but also by lost cargo capacity and reduced operational efficiency.

Fire Detection systems

The interview results indicate that no specific fire detection systems for BEV fires are currently implemented in terminals or vessels which show no additional cost allocation for BEV fire detection and technologies related to it.

From a theoretical perspective, advanced detection technologies have been given greater importance for BEV fire risk. Existing studies highlight that in dynamic environments, image-based systems and Near-Infrared (NIR) cameras carry out better fire detection solutions than conventional sensors, offering fairly low-cost and effective early fire detection solutions.

In contrast, interview findings show a strong dependence on conventional fire detection systems. Five out of six interviewees stated that no BEV specific detection systems are in place, and detection primarily depends on existing infrastructure. In open parking areas, the most common practices stay as manual fire patrols and visual smoke detection. Only one interviewee (A2) confirmed a basic level of monitoring, combining cameras with human surveillance:

"We have cameras around the area, and then we have, yeah, guards walking around."

This comparison points out a clear gap between literature studies and industry practice. While literature promotes cost effective and technology-driven detection systems, the industry remains largely dependent on manual and conventional approaches with limited additional investment for BEV transport.

Overall, this suggests that although advanced detection technologies exist and it could be implemented with moderate investments, the adoption in practice limited due to continued reliance on traditional detection methods aiming to control costs. Therefore, fire detection for BEVs still remains more operationally driven than technology-driven, which may delay early detection and influence overall risk management effectiveness.

Fixed fire Extinguishing sprinkler systems

The interview results indicate a clear variation in fire extinguishing approaches between vessels and terminals, which has significant implications for cost assignment.

From a literature standpoint, the fire extinguishing practices are majorly water-based fire protection systems, such as sprinklers that prevents fire spread between vehicles. In addition, theoretical assessment also highlights other methods, such as liquid nitrogen, fire blankets, dry chemicals, and carbon dioxide, can help in specific situations, especially in early stages of the fire.

Conversely, interview results show a divided fire extinguishing approach between the RoRo terminals and vessels which in turn has a significant impact of costs involved in it. Due to the confined nature of vessel spaces, there is a need to install appropriate fire-fighting systems based on the type of vehicles carried, which contributes to higher costs associated with transporting BEVs onboard. Interviews with shipping line representatives confirm the additional investments in BEV-related fire protection equipment. Interviewee B1 also mentions costs associated with supplementary onboard systems: ***"I think we spent some 25-30 thousand EUR in additional equipment, and it was fire blankets. It was this special nozzle head you could say that you connect to the fire main. There was some clothing for the crew and additional hoses and things like this"***

In terminals, the approach is more reactive and financially conservative. Two out of six interviews indicate reliance on basic firefighting equipment, such as fire blankets and external emergency response. But Interviewee B2 estimated the cost of a fire blanket is approximately €3,000. Interviewee A1 emphasized the absence of specialized BEV firefighting systems and complete reliance on fire departments: *"**No, we don't have… any special firefighting equipment for BEVs" and "we are closely nearby to the local fire brigade, but we don't have it inside the terminal**."* Notably, the dependance on local fire brigade intervention is not emphasized in literature, which highlights a gap between theoretical frameworks and operational reality.

Overall, this concludes that fire extinguishing practices are strongly influenced by area constraints and cost considerations which result in unequal investment levels. The vessels prioritize system-based protection due to higher onboard risk, and terminals adopt more cost-efficient and reactive approaches, which may limit initial response capability but reduce direct infrastructure costs.

Safety training

The results indicate that safety training is recognized as an important part in transportation of BEV, which is acknowledged in both literature and current practices. However, its implementation and associated costs differ between different stakeholders involved.

From a literature perspective, regular safety training and firefighting drills are considered essential for enhancing crew competence in handling fire incidents. It also emphasizes that repeated drills improve communication, coordination, and response time, thereby increasing overall effectiveness during emergencies.

In contrast, interview findings show limited and uneven practices of safety training in reality. Only two out of six interviewees explicitly highlighted the importance of safety training, with

some indication of additional costs. For example, Interviewee A3 reported the implementation of a BEV-specific training program at the terminal, with an estimated cost of 300–400 USD per person per course, focusing on basic awareness and early identification of fire risks: ***"Your general workforce doesn´t need to have any specific knowledge or requirements in that way, but some safety awareness, as in you know what to look for signs in case of fire issues. What happens if this? So there´s some basic education there. Course wise, they´re about 300 to 400 USD per person on the BEV safety".*** **(Interviewee A3)**

Similarly, the shipping lines respondent Interviewee B2 also supported an additional safety training which has been added in the vessel's safety training programs with no additional costs involved in it. Interviewee B2 mentions: *"**We have also done additional training on all vessels, one round on all vessels and there will be more such sessions. We have also invested in some certain equipment triggered by the introduction of electric cars**."*

In contrast, two out of six interviews also reported minimal investment is safety training and higher reliance on the organization's safety management system (SMS) with the written guidelines rather than proper structured training. Interviewee A1 and Interviewee A2 do not mention BEV-specific changes to terminal SMS and describe a largely informational approach. Interviewee A2 mentions: *"**We have the safety management, manuals and instructions made for the EVs, but it's for the pre-delivery inspections, and is no special training".***

This comparison gives a gap between theoretical recommendations and practical implementation. While literature strongly promotes continuous training while the industry practice often relies on low-cost training or informal approaches, especially in RoRo terminals. In general, although safety training is widely recognized as beneficial, its implementation is influenced by cost considerations and operational priorities. As a result, training practices can remain inconsistent within different actors within the industry where some are investing in structured programs (onboard vessels) while others adopt minimal-cost approaches (terminals).

<u>Insurance premiums</u>

The results show that while insurance risk associated with BEVs is acknowledged both in literature and practice, the impact on insurance premiums remains inconsistent and evolving across the RoRo industry.

The literature mentions insurance costs for BEV transport are expected to increase due to the higher fire risk linked to lithium-ion batteries and the potential severity of fire-related damage. The literature also emphasizes that insurers investigate not only the probability of fire incidents but also the scale and complexity of potential losses, suggesting upward pressure on premiums.

On the contrary, interview findings reveal a more divergent and context-dependent reality. A shipping line Interviewee (B1) reported that no direct increase in insurance premiums has been observed for vessels carrying BEVs, indicating that risk is not priced at an individual asset level, interviewee B1: ***"We haven't seen any increases in cost for insurance. If they see a risk that is increasing, they would just increase the premium for that type of vessel straight. You don't get an extra premium just because you carry BEVs."***

However, interviews with insurance consultants (C1, C2, C3) partially align with the literature studies, highlighting a dynamic and provisional market response. Initially, limited market knowledge and reduced insurer participation led to increased premiums, as mentioned by interviewee C1: **"A lot of the insurance companies just backed off… when you don't have many insurers, there is not much capital, then the price goes up."** At the same time, recent developments indicate that premiums rates are beginning to stabilize as more insurers re-enter

the market: ***"It's going up, but now it's flattening out… we actually have more insurers now willing to insure cars which is a sign that is flattening out."*** **(Interviewee C1)**

Additionally, interview findings reveal alternative risk management strategies currently being applied on a practical basis. For example, terminal operators may transfer insurance responsibility to the OEM´s by avoiding direct exposure to BEV related risks and associated insurance costs. It is highlighted by Interviewee A2: ***"we have nothing to do with the insurance… it will not be our insurance. It's the OEM's insurance."***

This comparison highlights a clear gap between theoretical expectations and current common practice. The literature anticipates higher insurance costs due to increased risk; actual premium adjustments appear uneven and are often managed at a portfolio or large scale rather than per asset.

Overall, this suggests that although BEV-related risks are recognized, their financial impact on insurance premiums is currently indirect, stabilizing, and strategically managed, rather than consistently reflected in higher direct costs for operators.

4.3 Infrastructure cost at RoRo port terminals

The results analyzed in this sub part is highlighted in two cluster points which cover the infrastructure costs of Charging stations and Parking space.

Charging stations

Two out of three interviewed terminal operators (Interviewee A2 and Interviewee A3) mentioned having charging facilities in the terminal. Interviewee A3 mentioned having 6 charging stations costing about 60,000 USD to install which was funded through partnership with port authority. Terminal operator interviewee A2 informed them that their terminal had invested in 90 charging stations primarily for importing cargo and pre-delivery inspections. Interviewee A2 interestingly added ***"this is a significant investment due to the scale and the need for power infrastructure".*** It was further added if more charging stations needed to be added ***"careful management is required to avoid exceeding available power, especially as other vehicles and future vessel connections may also require charging***." This goes along with the published literature exactly addresses the concern mentioned in the literature review chapter 2.3.1 of this research where the increasing number of BEV´s and demand for electric power can lead to bottleneck in electric grid infrastructure.

Furthermore, when it came to charging costs of the BEV´s it was mentioned that it would vary depending on the percentage of charge required but also clarified the cost would also include the labour costs. For example, as interviewee A2 mentioned ***"Charging costs around 41USD per vehicle as basic charge but depending on the percentage required, and rates charged to customers would reflect both labor and electricity costs".*** Interestingly, while interviewee A3 also mentioned along with the electricity costs the terminal would also add a charge its customers where it was mentioned ***"additional charge for monitoring and handling of BEV."*** This goes along with the published research where the terminals should have consideration to the increased load and electricity costs when making a investment in BEV charging station.

On the other hand, ship operator interviewee B2 and Ro-pax operators' interviewee B1 mentioned there were no investments made into charging facilities, rather than mentioned it should be done by terminal operators. While Terminal operator interviewee A1 mentioned

"Charging services are not offered due to logistical challenges, cost concerns related to fluctuating electricity prices". This feedback is in contrast with literature review as no techincal investment is done by the terminal due to being a early mover in the industry.

Parking spaces

When it comes to the weight of the BEV, it was mentioned and acknowleged in all the interviews that BEV weighs heavier than an ICEV which goes along well with the published research. For example, Interviewee A2 mentioned ***"BEV´s are about one ton heavier than internal combustion engine vehicle which impacts storage and vessels draft calculations".***

However, terminal operator interviewee A3 mentioned having a multistorey garage where increased weight of BEV over ICEV is a cause of concerns. Due to multistorey garages having weight limits it would require careful cargo staging which in turn may require structural upgrades or operational adjustments. To accommodate heavier BEV´s t was further acknowledged that this concern could lead to non-usage of storage space due to increased weight which goes along with the literature review chapter 2.3.2 whereas BEV´s are heavier the concept of live loads measure for multistorey garages is needed and considered safe.

Furthermore, Interviewee A3 mentioned ***"It will be hugely expensive to rebuild a multi-storey parking space that can fully hold BEV´s and make it structurally stronger from fire "*** which is In line with published research where it is acknowledged BEV fire pose significant threat to structural member of parking garages and it is needed additional fire resistance methods to further improve fire resistance performance of BEV car parks.

5. Discussion

In this section, results will be discussed based on results of the study related to current knowledge and practical implications (Abratt, 2020). The discussion of this study will address the results of three categories (see figure X, section 3.2.1).

Discussing the first feature of Cost of logistics operation for shipping of BEV´s, one of the main highlights point that should be noted operation of BEV´s is practically no different from any other vehicle. It was acknowledged in all the interviews that handling, loading and discharging operations was the same as the internal combustion vehicles. Even if it is mentioned in the literature review chapter 2.1 about special attention needing for BEV to avoid collision and damaging battery (Bao et al.,2023) that could in turn lead to costs, the interviews results (chapter 4.1) show that there was no special attention given to the BEV´s or any reduction of driving speed especially for BEV while loading and discharging on vessels which means there was no time loss or extra costs when it comes to handling of BEV. However, as mentioned in the in the literature review (chapter 2.1) the maritime ports in order to cater for the rapidly growing BEV´s will need to make organizational adjustments (Fredouet,2024) which is acknowledged in the interview results with addition of technical roles in the terminals for handling the technical issues and carry out inspections of BEV´s. Hence, that being a additional costs that terminals have to bear due to addition of BEV´s. Lastly, in regard to this feature of the analysis model, the literature review states the terminal will to invest in personnel training (Fredouet,2024). This goes along with one of the interview results of the terminal. This therefore is an additional cost when it comes to logistics operation for shipping of BEV´s.

With regards to the safety costs, the literature review identifies safety related costs as a central financial consideration in the RoRo shipping BEVs, largely due to the distinct fire behavior of lithium-ion batteries, including thermal runaway, prolonged cooling times, and the risk of re-ignition (e.g., Brzezinska & Bryant, 2022). The literature also gives a focus towards having an in-depth fire safety framework which involves BEV and has financial implications. Interview results (Chapter 4) confirm the unpredictable nature of BEV fires and have a framework to deal with fire safety. Since there is no standardized policy or framework, the measures taken by the RoRo stakeholders vary. While the literature highlights preventive investments such as vehicle spacing, monitoring, and location specific structural requirements (Chapter 2.2.1; Bisschop et al., 2019), the interviews indicate that industry practice favors different operational measures such as crew patrols, infrared thermal screening, segregation, and procedural controls. These strategies are perceived as more cost-efficient than structural changes, particularly pain point of increased vehicle spacing, which interviewees explained as economically limiting due to reduced terminal capacity or cargo intake onboard vessels (Chapter 4.2).

Regarding fire detection, the literature promotes image based near infrared systems (NIR) as effective, low-cost early warning solutions (Burnett & Wing, 2018; Qiao et al., 2025). However, interview results (Chapter 4.2) show limited BEV specific investment in detection technologies, with most terminals relying on patrols, visual surveillance, and existing camera systems. This suggests a gap between theoretical recommendations and implementation driven by understanding the actual need of the NIR system when the traditional measures can be sufficient and also cost-benefit considerations. However, it would be interesting to see if this gap will continue as it is or will change in the future when most of the terminals/vessels will be occupied with only EVs.

Fire extinguishing measures portray the most tangible safety related costs, particularly onboard vessels. The interviews closely align with literature emphasizing water-based suppression systems as the most effective method for controlling BEV fires even after having high retrofit and installation costs (Boehmer et al., 2021; Hynynen et al., 2023). Shipping companies reported investments in specialized equipment such as fire blankets, nozzle systems, protective gear making clear BEV related cost implications. The main reason the shipping companies took these costs is because BEV is in the vessel which is a confined space and the risk of fire damage is more if the vessel is at sea. In contrast, terminals having mostly BEV in open space and having options for firefighting tend to rely on local fire brigades, thereby capping the direct expenditure of extinguishing but increasing dependence on external emergency response (Chapter 4.2). This brings to the gap in the real world where the regulatory bodies or the insurance companies are not enforcing the terminals to have proactive extinguishing systems at the terminal rather than having an external source for extinguishing fire which delays the response. Some terminal interviewees also mentioned that if a BEV fire starts, they remove the nearby cars from trying with a fire blanket or let the EV burn alone until external assistance comes. This shows that terminals have the leverage of time, space nearby fire department which gives them cost-saving advantages.

Lastly, safety training and insurance costs unfold from the separation between theory and current practices. While Chapter 2.2.5 stresses regular training as critical for effective fire response which also includes BEV (Sima et al., 2019), interviews show mixed implementation, ranging from BEV specific courses to minimal updates within existing safety management systems (Chapter 4.2). Since the vessels have BEV specific fire extinguishing equipment's onboard it forces them for mandatory and regular safety training which makes onboard crew well prepared for firefighting. This also opens the possibility that if terminals start having a new BEV-related safety equipment's the crew must go under mandatory training which will have certain implications for cost. Similar deviation for insurance costs where the literature anticipates increased insurance premiums due to higher fire severity (Unobe et al., 2024), interview findings indicate that BEV risk is largely priced at a portfolio level, with premiums stabilizing as insurer understanding improves. Since the knowledge of insurers improves, this gives a possibility for reduction in insurance premiums with the condition that terminals or vessels improve the safety measures toward the BEV which eventually reduces the risks involved in transportation.

Regarding the third feature of Infrastructure costs for RoRo port and terminals, one of the focuses was additional costs or investments terminals needing to make for installation of charging stations to become the early movers for management of BEV´s (Fredouet,2024). As mentioned in the literature review (Chapter 2.3.1) that increasing number of BEV´s and demand for electric power can lead to bottleneck in electric grid infrastructure (Straub et al. ,2021).This was acknowledged in the interviews (Chapter 4.3.1) that the it is a significant amount for investment in the charging stations for BEV´s , it also was needing to have a careful management if more charging stations need to be added due to avoid exceeding of the power, as future vessels might need shore power connections as well. This installation of charging station would also lead to additional electricity costs for the terminals to charge the BEV´s. The recovery of these costs would also vary depending on the charging needed by a BEV and the labor costs. Furthermore, as mentioned in the literature review chapter 2.3.2 the weight of BEV´s is much higher than the ICEV´s (Sandrini et al.,2025). Which was acknowledged in the interview (chapter 4.3.2), it was also mentioned that due to these infrastructural upgrades or operational adjustments might need to be made in multistorey garages to accommodate for heavier BEV´s as multistorey garages have weight limits that require careful cargo staging. This could then lead to additional cost for terminals either to rebuild a stronger multistorey

garage to accommodate heavier ever rising BEV´s or have additional costs of not filling the old garages up to its full capacity as an operational adjustment to accommodate the BEV´s. And lastly, as BEV fires pose significant threat to structural members of the car park (Kang et al.,2025) as it burns at a higher temperature than a ICEV (Heo et al., 2025) it was acknowledged in the interview (chapter 4.3.2) there was a need for making structural changes in the multistorey car parking spaces holding BEV´s. Therefore, needing for terminals to have additional infrastructure costs for strengthening BEV car parking space to withstand BEV fires.

6. Conclusions

To find the solutions to the research question for this research, a literature review was done following with interviews conducted with three (3) terminal operators, two (2) RoRo Shipping lines, one (1) insurance company and a total of nine (9) interviewees participated in this thesis.

For RQ1 ´*What costs for logistic operations exists in RoRo shipping of BEV´s?* ´ ,

The results show that there is no difference in speeds of BEV´S and ICEV´s when loading and discharging on or off from the vessels which does not directly impact on the costs during operation and handling of BEV´s. However, it was identified in the interviews that there are specific BEV training courses available for Stevedores, which is a cost for terminals. Additionally, in the interviews it was clear that port and terminals are having to make organizational changes, i.e. addition of technical roles for inspection, checks and resolving technical issues before loading on vessels and after discharging them from the vessels. That addition of role contributes towards the costs for logistic operations in RoRo shipping of BEV´s.

RQ2: *What costs of safety measures exist in operational RoRo shipping of BEVs?*

The findings show that fire safety costs are significant but have an uneven financial component where magnitude and nature vary significantly between vessels and terminals. While the literature emphasizes structural investments with more vehicle spacing to address preventive BEV fire risks the current industry prioritizes operationally flexible and cost-efficient measures such as regular patrols, segregation, procedural controls, and reliance on existing systems like infrared thermal screening. Fire detection related costs remain limited, as results from interviews indicate most terminals continue to use conventional surveillance and monitoring rather than BEV specific equipment or systems due to cost–benefit considerations. There is a contrast in fire extinguishing measures that stands for the most significant direct costs, specifically onboard vessels where cargo holds have confined environments and limited external assistance during voyage gives them the need for investment in water-based suppression systems, specialized equipment, and mandatory crew training for BEV firefighting. The RoRo terminals which operate in open spaces have access to external emergency response i.e. local fire brigades and minimal fire equipment like fire blankets incur lower direct costs benefiting from greater spatial and operational flexibility. For safety training the vessels have a recurring cost due to mandatory BEV fire safety training linked to specialized firefighting equipment and since terminals rely on existing safety systems the costs in limited but to increase if BEV specific safety equipment is introduced. Regarding insurance premium cost, interviews indicate that BEV risks are greatly priced at a portfolio level and premiums are stabilizing as risk understanding and safety measures improve.

For RQ3 ´*What costs related to terminal infrastructure development should be considered in RoRo shipping of BEVs*? ´,

The results show that the terminal will need to invest in the charging infrastructure to cater for service of increasing BEV´s. This charging infrastructure comes with substantial costs for the terminals and upon that it was highlighted that installation of the charging infrastructure would be higher as well. The electricity costs for which the terminal operators need to have recovery of these costs from its customers that would also vary depending on the charging needed by a BEV and the labor costs. Additionally, if the terminals must add or expand the charging infrastructure, it will require careful management to avoid exceeding the power from the grids. Furthermore, due to the increased weights of the BEV´s the port and terminals with multistorey car parking spaces need to evaluate its weight limits that require careful cargo staging. By this either terminal operator has to make infrastructural upgrades of multistorey parking which would result in heavy costs, or the terminals would not be able to fill up the multistorey garages to its full limits, which is in turn a loss of capacity costs. Lastly, due to high burning temperatures the threat of BEV fires is significantly higher compared to the ICE, therefore the car parks or the multistorey garages will have to make structural changes which require more strengthening to the infrastructure which in turn can lead to additional costs for terminals due to the BEV´s.

6.1 Practical Implications

The findings of this study give several practical implications for RoRo ports, terminals, and shipping lines. Firstly, organizations should account for cost increases related to safety, particularly the need for greater spacing between or with BEVs and investments in fire detection and extinguishing technologies due to special nature of BEV fire risks. Secondly, operational adjustments and necessarily having a specialist BEV technical staff and targeted training for all BEV handling personnel which should be implemented to ensure safe handling of BEVs. Furthermore, ports and terminals may need to plan infrastructure upgrades, such as charging facilities and reinforcement of parking structures, to accommodate the specific characteristics of BEVs. Overall, a proactive and adaptive approach is recommended to effectively manage the evolving cost of drivers associated with the increasing transportation of BEVs in the near future.

6.2 Suggestion for further research

For future research, more interviews with a wider number of ports and terminals can be conducted as the validity and the reliability of this thesis cannot be generalized or applied at a global level. More interviews will provide more validity and reliability for this topic. Similar study could be done for Hybrid electric vehicles, for Battery electric trucks or high and heavy machinery. A study about indirect costs for ports and terminals due to shipping of BEV´s can be conducted to provide further financial consideration of this study. Furthermore, the cost's structure could also be applied for the research of inland transportation segment from the Manufacturers to the freight forwarders or from Freight forwarders to the dealership companies.

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Appendix

Appendix 1 – Assignment questions to the interviewees based on segment.

Interview Questions	RoRo Terminal	Shipping Line	Insurance company	Research question
Describe infrastructure at terminals especially for EV´s? Are there any investments made into it? Organizational changes?				RQ1
Challenges faced on operational level with EV´s in ports and terminals? Affect on turnovers? Financial impacts?				RQ1
Is there any training programme for safe handling EV´s? Cost aspects?				RQ1
Describe Inspections/ safety and quality checks of EV´s? Additional cost involved due to it?				RQ1
Are there any SMS (Safety management systems) in place for EV´s?How is that broken down into costs?				RQ2
Special preparations for EV´s in ports and terminals (Fire detection,Fire prevention,Fire Fighting,trainings)?Additional cost involved?				RQ2
Insurance costs considering Fire risks of EV´s? Additional premium?				RQ2
Are the any Future investments in relation to safety measure of EV´s?				RQ2
Describe the current infrastructure? Changes made / will be specially for BEVs? Breakdown of cost aspect?				RQ3
Consideration investments charging stations for EV´s?				RQ3
Infrastructural changes due to increased weight of EV´s? Multi-storey garages?				RQ3
Investment in structures of car park? Insurance costs?				RQ3