CHALMERS

Evaluation of charging infrastructure for electric trucks in the European Union

Navigating the Electrified Road: A Systematic Literature Review of Electric Truck Infrastructure in Europe

Bachelor thesis for International Logistics Program

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CHALMERS UNIVERSITY OF TECHNOLOGY
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PREFACE

We are pleased to deliver this report as the completion of our studies in the International Logistics program at Chalmers University. This report is the culmination of our final project, a mandatory 15-credit requirement to fulfill our 180-credit degree.

Throughout this project, we faced moments where it was necessary to make methodological adjustments. Successfully managing the demands of academic rigor while facing personal issues was a difficult task. However, we persevered with unwavering determination, successfully sailing through the difficulties.

We want to extend our heartfelt appreciation to our supervisor, Fredrik Olindersson, from Chalmers University, for his essential guidance and support throughout this project and to our examinator Olle Lindmark from Chalmers University , for his contributions to our effort. In addition, we would like to express our gratitude to the staff at the pertinent establishments for their time and invaluable contributions to our effort.

This report has provided us with a valuable learning opportunity, and we appreciate the assistance and guidance from all those who contributed to its finalization.

Kenan Olevic & Antonijo Peshevski

Gothenburg, May 2024

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SAMMANDRAG (in Swedish)

Den europeiska gröna given fastställer ambitiösa klimatmål, där bland annat införandet av elektriska lastbilar som ett medel för att minska utsläppen inom transportbranschen omnämns. Ett väsentligt krav för att kunna förverkliga denna elektriska övergång är kravet på omfattande, tillgänglig och robust laddningsinfrastruktur för att underlätta införandet av el-lastbilar i hela Europeiska unionen.

Denna studie undersöker de krav och hinder relaterade till införandet av elektriska lastbilar för långdistanstransporter i Europeiska unionen. För att kunna analysera dessa krav och hinder så har en systematisk litteraturöversikt utförts. Resultatet av studien visar att faktorer som utökad batterikapacitet, effektiviserad laddningsteknik och en omfattande utbyggnad av laddningsinfrastruktur är avgörande för förverkligandet av övergången mot implementeringen av elektriska lastbilar för långdistanstransporter i EU.

Resultatet visar även att de hinder som nämns i studien enbart kan övervinnas ifall beslutsfattare och branschaktörer för transportbranschen väljer att samarbeta på ett samordnat sätt. Strategiska investeringar i infrastruktur och skapandet av ett nytt rättsligt ramverk till förmån för transportföretag kan hjälpa övergången till elektriska lastbilar. Dessa rättsliga ramverk bör vara i linje med EU:s klimatmål och till för att främja för en hållbar framtid för godstransporter inom EU.

Det är viktigt att nämna att social hållbarhet och energibehov inte beaktas i denna studie.

Keywords: Battery, electric, truck, charging, infrastructure, EU, requirements, barriers, implementation

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ABSTRACT

The European Green Deal establishes ambitious climate objectives, including adopting electric trucks as a crucial element in reducing emissions within the transportation industry. An essential aspect of this shift is the requirement for a robust and reliable charging infrastructure to facilitate extensive adoption throughout the European Union.

This study investigates the requirements and barriers related to adopting electric trucks for long-haul transport in the European Union. To achieve this result, a systematic literature review was conducted. The result shows that for the implementation of electric trucks for long-haul in the EU, the battery capacity, the charging technology, and a massive buildup of charging infrastructure are crucial for the transition. Furthermore, the difference in initial investment for acquiring an electric truck and a diesel truck is still significant.

To overcome these obstacles, policymakers and industry players must work together in a coordinated manner. Strategic investments in infrastructure and the creation of a new legal framework in favor of transport companies can improve the shift to electric trucks, which aligns with the climate goals of the European Union and promotes a sustainable future for transporting goods.

It is essential to mention that the study does not consider social sustainability and energy demand.

Keywords: Battery, electric, truck, charging, infrastructure, EU, requirements, barriers, implementation

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ACRONYMS AND TERMINOLOGY

ACEA	European Automobile Manufacturers Association
BET	Battery electric truck
CO2	Carbon Dioxide
EU	European Union
GHG	Green House Gas
MCS	Megawatt Charging System
RED	Renewable Energy Directive
SSB	Solid state battery

1. INTRODUCTION

Over the past 150 years, global temperatures have increased by 1.2 Celsius above preindustrial levels, and carbon dioxide (CO2) emissions have experienced an increase of 150 times when compared to the levels recorded in 1850 (Friedrich & Damassa, 2014). The increase is primarily attributed to human activities, such as burning fossil fuels and industrial processes that release greenhouse gasses (GHG) into the atmosphere (Friedrich & Damassa, 2014). This has led to global climate change and increased Earth temperature over the past century. In response to the escalating environmental concerns, discussions culminated in the signing of the Paris Agreement at the UN Climate Change Conference (COP21) by 196 nations. The primary goal of the agreement is to limit global warming to well below 2 degrees Celsius above pre-industrial levels, with efforts aimed at restricting the temperature increase to 1.5 degrees Celsius (United Nations [UN] 2017).

The agreement aims to strengthen the global response to climate change by significantly reducing GHG, with each country setting its target for emission reduction (UN 2017). The European Union (EU) and all the member states have signed and ratified the Paris Agreement and are firmly committed to its implementation (European Commission [EU], 2024). In line with this commitment, EU countries have agreed to set the EU on course to becoming the first climate-neutral economy and society by 2050 (EU, 2024). In the first phase, the EU will aim to reduce at least 55% of GHG emissions by 2030, compared to 1990 levels, and plant three billion additional trees in the EU by 2030 (EU, 2023).

In 2020, road transport contributed to 24% of the total emissions of CO2 in the EU, which is the primary GHG (Lantz & Joelsson, 2023). Going further to the aim of the study of this paper, heavy-duty vehicles are responsible for 25% of the total road transport CO2 emissions and more than 6% of the total GHG in the EU (EU 2023). The demand for road transport is projected to surge in the coming years, increasing by approximately 1 % annually until 2050. This trajectory forecasts an 8 % rise in CO2 emissions from road transport (Lantz & Joelsson, 2023).

Decarbonization will be crucial for road transport to contribute to global emission reduction while meeting the rising transport demand (Lantz & Joelsson, 2023). Many heavy-duty vehicle manufacturers have set an ambitious goal to introduce more zero-emission vehicles into the rapidly expanding market (Lantz & Joelsson, 2023). These targets suggest that 40% of all sales in 2030 will comprise battery-electric or fuel-cell vehicles (Lantz & Joelsson, 2023). Nevertheless, transitioning to a zero-emission road freight sector faces numerous technical, operational, and financial challenges.

1.1 Aim of the report

This report aims to evaluate the requirements for the transition towards electric trucks for long-haul transport. Requirements for the deployment of the charging infrastructure will also be analyzed. The barriers against the electric truck transition and the deployment of charging infrastructure will also be examined. Since many legislative measures currently propelling this electric truck transition are coming from the European Union, this report will take a European angle in its analyses. With that said, the scope of this research has the European Union in mind. Some of the research papers analyzed have specifically considered European countries. The results of this study may be applied as a direction for future researchers looking into other parts of the world and not exclusively for the European Union.

1.2 Research questions

The research questions for this report are the following:

> -What are the necessary requirements enabling the transition to fully electric long-haul transport and the implementation of an electric charging infrastructure?
>
> -What are the barriers to the transition towards fully electric long-haul transport and the implementation of charging infrastructure?

1.3 Delimitations

The first delimitation regards the electric grid. All the requirements and barriers mentioned presuppose that the electric grid capacity will suffice to support the charging infrastructure networks. This report will not answer whether that assumption is feasible or not. The subject of electric grid capacity for electric truck charging infrastructure deserves its own dedicated thesis project.

The second delimitation regards the social sustainability effects of the predicted transition towards electric trucks for long-haul. Even though the subject is slightly touched upon in the research papers analyzed, it is also a complex and multi-faceted subject that, due to its many complications and layers, needs its own thesis project to do it justice.

2. THEORY

Over the past decade, electric vehicles have gained in popularity, but their market share is still relatively low. This chapter will cover the historical developments of electric trucks, the various forms of battery types, charging options, the environmental legal framework within the EU, and the specific framework for some EU member countries.

2.1 History of battery electric truck

The concept of electric vehicles, including trucks, dates to the early 19th century (Desmond 2020). However, the modern development of electric trucks gained momentum in the late 20th and early 21st centuries due to growing concerns about air quality, fossil fuel dependence, and climate change (Desmond 2020). An electric truck is a commercial vehicle powered by electricity rather than traditional internal combustion engines fueled by gasoline or diesel (Cunanan et al., 2021). A battery electric truck (BET) converts the chemical energy stored in active materials into electrical power within the electrochemical cells (Pelletier et al., 2014). Batteries differ from fuel cells because batteries have the active material stored within the system, while fuel cells have the active materials continuously fed into the system (Pelletier et al., 2014). BET's batteries are often composed of lithium-ion cells due to their high energy and power density (Cunanan et al., 2021).

The large battery is charged from the electricity grid, and the powertrain is simple in design (Pelletier et al., 2014). Benefits include the absence of tank-to-wheel emission, high energy efficiency, and much less operating noise (Pelletier et al., 2014). On the other hand, technical disadvantages include a relatively low achievable range and the long time required to charge the batteries because of their low energy density (Pelletier et al., 2014). BETs have fewer moving parts than internal combustion engine vehicles and do not need regular oil changes (Feng & Figliozzi, 2013).

2.2 Policy and regulatory framework

A policy instrument is a tool governing authorities utilize to influence different actors toward achieving specific political goals and agendas (*Policy Instruments | IPBES Secretariat*, n.d.). Well-structured policy instruments are crucial for overcoming obstacles in the initial phases of electrifying road freight (Lantz & Joelsson, 2023). According to Lantz & Joelsson (2023), there are three different categories of policies:

1. *Administrative policies* consist of rules, laws, directives, standards, and agreements that guide how things are done.

2. *Financial policies* that aim to influence behavior by changing the prices of goods and services. They include measures like subsidies, taxes, and grants.

3. *Information policies* that focus on increasing knowledge to help people make better decisions. They involve activities such as public disclosures and educational initiatives.

To delve further into the issue, this paper aims to address and examine the policies and the regulatory framework of the EU and the EU member states.

2.2.1 European Union policy and regulatory framework

Aligned with the Paris Agreement, EU leaders have embraced the goal of achieving climate neutrality In the EU by 2050. This goal led to the birth of the *European Green Deal*, an extensive arrangement of policy measures created to steer the EU towards a transition to increased sustainability (EU 2019). The European Green Deal encompasses various sectors, including climate, environment, energy, transportation, industry, agriculture, and sustainable finance (EU 2019). The European Green Deal represents a united European effort for a sustainable future (EU 2019).

As a part of the European Green Deal, the EU Commission proposed the *first European Climate Law* on March 4, 2020 (EU 2019). As a first target, GHG emissions within the EU should be reduced GHG by at least 55% by 2030 compared to 1990s levels. (EU 2018). There are no targets for specific sectors, but the European Commission states that the transportation sector must reduce GHG emissions by 90% by 2050 for the EU to reach its goal of climate neutrality. (EU 2019).

Fit for 55 is a legislative package unveiled by the European Commission in July 2021(Wilson, 2022). It consists of a multitude of legal proposals aimed at updating the transport, energy, and climate-related laws within the EU to match the objectives outlined in the European Green Deal and its climate legislation targets (Wilson, n.d.). The proposed revisions related to transport include:

- The EU Emissions Trading System (EU ETS) is a crucial policy instrument designed to reduce the release of greenhouse gas emissions inside the European Union (EU n.d). The system operates based on a cap-and-trade premise, which involves limiting the quantity of specific greenhouse gases released by designated businesses, such as power plants and companies (EU n.d). These entities are assigned or obligated to acquire emission allowances, which they can exchange with one other (EU n.d). This encourages the decrease of emissions by offering rewards to individuals who pollute less and allowing industries flexibility in achieving their targets (EU n.d). The EU ETS is essential for promoting decarbonization across multiple sectors (EU n.d).

- The Renewable Energy Directive (2009/28/EC) is a regulatory framework implemented by the European Union to encourage the utilization of renewable energy sources for power, heating, and transportation (*Renewable Energy Directive*, n.d.). The directive establishes mandatory objectives for EU member states to raise the proportion of renewable energy in their total energy consumption (*Renewable Energy Directive*, n.d.). The directive specifies the criteria and regulations for implementing renewable energy, such as providing support mechanisms, establishing sustainability standards for biofuels, and facilitating collaboration between member states (*Renewable Energy Directive*, n.d.). The Renewable Energy Directive (RED) seeks to promote the growth and use of renewable energy sources, including wind, solar, and biomass, to decrease greenhouse gas emissions, improve energy security, and foster economic expansion in the EU (*Renewable Energy Directive*, n.d.).

- The Energy Tax Directive CO2 Emission Standard for Cars and Vans ((EU) 2019/631) is a regulation policy implemented by the European Union to reduce carbon emissions from cars.(*CO_2 Emission Performance Standards for Cars and Vans - European Commission*, n.d.) It set goals for the average carbon dioxide (CO2) emissions generated by newly sold automobiles and trucks in the EU (EU 2018). Manufacturers are obligated to ensure that the vehicles they make comply with these emission requirements, which become increasingly strict as time goes on (EU 2018). The regulation also contains measures for energy taxation to promote the adoption of cleaner and more fuel-efficient vehicles by applying more significant fees on vehicles with higher CO2 emissions (EU 2018). This directive aims to reduce the environmental consequences of transportation and encourage the adoption of more environmentally friendly technologies in the automobile sector (EU 2018).

- The EU's Deployment of Alternative Fuel Infrastructure initiative aims to improve the availability and accessibility of infrastructure for alternative fuels, including electric car charging stations, hydrogen refueling stations, and natural gas filling stations (Fidanza ECR & Roman Haider, 2023). The primary objective of this effort is to overcome the obstacles delaying the mainstream acceptance of alternative fuel vehicles by guaranteeing that drivers have easy and convenient access to refueling or recharging stations throughout the EU (Fidanza ECR & Roman Haider, 2023). The EU aims to promote the adoption of cleaner and more sustainable transportation methods by investing in the creation and implementation of infrastructure (Fidanza ECR & Roman Haider, 2023). This investment will help reduce greenhouse gas emissions and decrease reliance on fossil fuels (Fidanza ECR & Roman Haider, 2023). Fidanza ECR & Roman Haider, 2023 mention that, at the same time, it will stimulate innovation and economic growth in the energy sector.

2.2.2 Policies and regulations of European Union member states

Several EU member countries are strengthening support for zero-emission heavy transport in national plans.

As the biggest economy in the EU, Germany aims to implement different policies and regulations in their legal frame to motivate and boost the implementation of zero-emission heavy vehicles amongst its Populus. The commitment of the Paris Agreement and EU climate law is translated into German climate law through the Climate Action Programme 2030 and the Climate Change Act (*Climate Action*, n.d.). The German federal government adopted the *Charging Station Ordinance, an administrative policy regulating the establishment of alternative fuel infrastructure* (*Federal Ministry for Economic Affairs and Climate Action*, n.d.). The directive puts rules in place to ensure specific technical requirements, e.g., harmonizing socket and payment standards for publicly accessible charging stations (*Federal Ministry for Economic Affairs and Climate Action*, n.d.).

The Electric Mobility Act is another initiative that presents further privileges for German companies or private individuals choosing to acquire electric vehicles or start utilizing public transportation deemed more environmentally friendly, such as subways or buses. (*Federal Ministry for Economic Affairs and Climate Action*, n.d.). The German federal government developed financial programs to improve the implementation of heavy-duty vehicles. Between 2021 and 2025, 1 billion EUR will be allocated to the automotive industry to renew fleets of heavy-duty vehicles. The renewal scheme aims to support more efficient and environmentally friendly fleets of heavy-duty vehicles (Lantz & Joelsson, 2023).

The State Aid is an economic aid provisioned by the German federal government as an incentive to encourage the purchase of light and heavy-duty commercial vehicles with climate-friendly propulsion systems and ancillary charging stations (Lantz & Joelsson, 2023). Through the aid, German haulers and transportation companies can be granted a purchase grant covering up to 80% of the additional cost of purchasing a zero-emission vehicle (Lantz & Joelsson, 2023).

The *toll rates* in Germany are based on three shares: air pollution, noise pollution, and infrastructure costs (*Toll & Toll Billing after CO2 Class Introduction: How to Determine the CO2 Class of Your Vehicle*, n.d.). In Germany, All BETs are entirely exempt from the toll system until January 1, 2026; after that, 25% of the toll rate will be due to infrastructure (EU,n.d). Assuming an annual mileage of 40,000 km, an electric truck would save more than 7,000 EUR annually or 36,600 over five years (Lantz & Joelsson, 2023).

Based on research conducted by Lantz & Joelsson (2023), one environmental policy has been noted for **Sweden** concerning the implementation and division of environmental administrative zones throughout the country. The policy, which is known as Miljözoner - Transportstyrelsen, regulated by 22 § in Trafikförordning (1998:1276), enabled Swedish Municipalities since 2020 to divide and implement certain geographical areas into so-called “Environmental zones” (Lantz & Joelsson, 2023). These zones were later divided into three groups (ranging from groups 1-3), where different environmental requirements occur for each group. (Lantz & Joelsson, 2023).

Beyond laws and regulations, specific investment programs can be noted in **Sweden**. Lantz & Joelsson, 2023 present one of these investment initiatives known as *klimatklivet.* This particular investment initiative consists of a more extensive portfolio of financial investments that support different types of actions that can be performed to reduce greenhouse gas emissions (Lantz & Joelsson, 2023). Part of these initiatives is funding the research and development of charging infrastructure for electric vehicles (Lantz & Joelsson, 2023).

Another one of these initiatives is the one called *klimatpremier för tunga lastbilar*.
This initiative consists of a motion given by the Swedish government to the Swedish Energy Agency. The goal of the said motion is for the Swedish Energy Agency to investigate and put forward guidelines for how the implementation and use of heavy electric trucks and trucks driven by alternative fuels (biogas and hydrogen) can be partially subsidized by the government (*Klimatpremie För Tunga Lastbilar,* n.d.).

The motion suggested that the government may subsidize 20 percent of the total cost of purchase and implementation of electric trucks for a company that chooses to acquire one. (*Klimatpremie För Tunga Lastbilar,* n.d.). Another option was for the government to cover 40 % of the additional miscellaneous costs arising upon purchase, such as maintenance or insurance (*Klimatpremie För Tunga Lastbilar*, n.d.).

Ireland's revised Climate Action Plan outlines specific goals, such as achieving a fleet of 700 low-emission heavy-duty trucks by 2025 and ensuring zero-emission heavy-duty truck sales account for 30% by 2030 (Energy Agency, 2024). The plan also includes provisions for heavy-duty vehicles (Energy Agency, 2024).

In 2025**, Denmark** will implement a tax system for trucks determined by their CO2 emissions (Energy Agency, 2024). This will serve as a direct and straightforward policy message to truck operators (Energy Agency, 2024).

The **Netherlands** has implemented a subsidy program dependent upon the type of vehicle and the firm's size (*Netherlands Introduces Subsidies for Electric and Hydrogen Trucks*, n.d.).

Major corporations are eligible for a refund of up to 40% of the extra expenses incurred while purchasing a diesel truck (Energy Agency, 2024). For enterprises with less than ten employees, the financial aid might amount to up to 60% of the discrepancy (*Netherlands Introduces Subsidies for Electric and Hydrogen Trucks*, n.d.).

2.3 Electric roads Technologies

A few charging infrastructure solutions are considered the most efficient for long-haul BET transportation. All these charging solutions involve the vehicle being in motion while simultaneously charging.

- **The Overhead Conductive Technique:** This charging technique is an old and established one with documented use in history (Konakati et al., 2022). The most notable use for this charging type has been tram/trolley transport (Konakati et al., 2022). The charging solution is comprised of an arm situated above the vehicle that is connected to a power source cable located above the vehicle (Konakati et al., 2022).
  This same method can be used as a BET charging alternative. The technology would have thus included a power cable network above a certain distance, where the cables would be connected to the electric truck throughout (Soares & Wang, 2022). By being connected, power would have been applied evenly throughout the distance, with the power cable network being placed approximately at least five meters above the ground (Fyhr et al., 2017).

- **Road-Bound Conductive Technology:** This charging technology type is similar to the previously presented one. In this instance, an electric charge is being drawn from beneath the ground (Soares & Wang, 2022). At the electric vehicle underside would an electric conductor arm be placed that would have been charged via magnets from the ground underneath (Soares & Wang, 2022). These magnets, once physically connected to the conductor arm, would have contained and been able to produce enough electric capacity to maintain an electric charge (Soares & Wang, 2022).

- **Inductive Charging Technology:** The third and final charging infrastructure technology type is the one known as inductive charging technology (Soares & Wang, 2022). In this case, a wireless charging solution was applied. This system contained an electric transmitter installed underground and an electric receiver at the opposite end, built into the electric heavy-duty vehicle (Soares & Wang, 2022). For this solution to be proven adequate, three key factors exist as prerequisites: an appropriate gap between the transmitter and electric receiver, a high and uninterrupted power supply, and even the traveling speeds of the vehicle involved (Fyhr et al., 2017). The charging time of this infrastructure technology type has been said to vary quite substantially since it depends on the factors mentioned above as well as the design of the electric truck itself regarding where the electric circuit is placed within the electric receiver on the underside of the truck (Soares & Wang, 2022).

2.4 Battery electric truck charging strategy

The following charging types being presented all contain stationary and static charging forms compared to the previously mentioned charging technologies.

- **Public Overnight Charging:** This charging type involves using static charging stations where the trucks are parked overnight while charging (ACEA, 2021). The stations, placed at various points along a given motorway, would provide a charging capacity of 100 kW (ACEA, 2021). The charging time would have to coincide with the natural end-of-shift time for the driver and thus be charged for the duration of the driver's resting period of 9 hours under the law of the European Union. (ACEA, 2021).

- **Higher Power On-Road Public Charging:** This type of technology for charging is the one that is commonly known as "fast charging" (ACEA, 2021). It involves shorter periods with a heavier charging capacity for maximum charging effect (ACEA, 2021). The suggested kW has been pointed out to be 350 kW (ACEA, 2021). There are also suggestions for increasing the kilowatt charge to 500-1000 kW. These charging stations are known as megawatt charging stations. ACEA (2021) points out that while 350 kW is acceptable, it should be a bare minimum limit.

  It is also indicated that the megawatt power charging rate is the most suitable (ACEA, 2021). The reason is that the given window of opportunity for fast charging will be narrowed when the predicted number of electric trucks increases by 2025 and, by extension, 2030 (ACEA, 2021). To avoid a bottleneck effect, these heavy-duty trucks would need to be able to charge faster as well as avoid queues at the charging stations (ACEA, 2021).

- **Battery Swapping:** In this alternative, stations would be implemented where the driver takes out the car battery, puts it into a charging position, and resumes driving by taking a fully charged battery at the station (Zhang et al., 2024). This strategy would include the detachment of the battery following a specific gear mechanism that would enable simple disengagement and application of a battery (Zhang et al., 2024).

  Zhang et al (2024), argue that the battery swapping method counts as a form of fast charging, but one that would be even faster than the previously mentioned alternative. Since the battery in charge can charge up after a period of time, it is suggested that stoppage and utilization rates of the battery swapping stations would be quite short in time (Zhang et al., 2024). The battery taken out would thus be charged for a long time and later be swapped out by another incoming driver. Zhang et al., 2024 also argue that this may also be lenient on the battery's lifetime since it is given the right amount of time to charge up (Zhang et al., 2024).

2.5 Technological innovation

The history of lithium-ion batteries goes back to the 1820s, when experiments with lithium-ion anodes were first conducted (Reddy et al., 2020). Early test results concluded lithium-ion anodes would serve well in batteries (Reddy et al., 2020). Lithium-ion batteries are used in automotive and truck engines due to their physical properties, such as low density, high energy-specific capacity, and low redox potential (Reddy et al., 2020). Lithium-ion battery developments were consistent during the 20th century but increased rapidly in the 1970s-1980s (Reddy et al., 2020). The cell format must be altered to improve a lithium-ion battery's density, energy capacity, and redox potential (Reddy et al., 2020). Several models for the cells have been developed over the years, each with advantages and disadvantages (Reddy et al., 2020).

Current-day lithium batteries for cars and trucks have the issues of low thermal capacity, high flammability risk, and sensitivity to temperature changes (Khan et al., 2023). The low thermal capacity may lead to overheating of the battery cells (Khan et al., 2023). A temperature shift may cause overheating and lead to a burnout of the battery cells (Khan et al., 2023). Lithium-ion batteries are known for having a high flammability risk since they may cause a chemical fire that is harder to extinguish than a regular fire and need specific tools as well according to Khan et al., (2023.)

To improve on this, several future implementations can be witnessed. Some manufacturers, like Tesla, argue that the cell format of current-gen lithium-ion batteries is at fault here (Ank et al., 2023). Tesla has chosen to deal with the previously mentioned issues of lithium-ion batteries by changing to a cylindrical cell format (Ank et al., 2023). The cylindrical format coupled with a thicker casing, double-sided coated electrodes, the use of graphite instead of silicone as an electrolyte, and an active internal cooling system is said to improve the thermal capacity, reduce flammability, and ultimately improve the range of the vehicles (Ank et al., 2023).

Other manufacturers, such as Toyota, say that the liquid or gel electrolyte of current-gen lithium-ion batteries need to be exchanged for a solid-material electrolyte (Khan et al., 2023). This type of battery, known as a solid-state battery, may increase thermal stability (Khan et al., 2023). The increase in thermal stability could mean that the overheating effect could be avoided (Khan et al., 2023). Solid-state batteries could also have a significantly lesser risk of flammability, increased energy density, and shorter charging times (Khan et al., 2023).

3 METHODS

The report followed a Systematic Literature Review (SLR) approach, which included qualitative data. The research took place over seven months, between November of 2023 and May of 2024. The research took place in Gothenburg, Sweden. Access to the data used was granted through the services provided by Chalmers Library. Access to specific programs and databases was given as a part of the bachelor's thesis course.

3.1 Scope of the study

The scope of this study was to determine the specific requirements needed for the implementation of charging infrastructure based on the predicted increased usage of heavy electric vehicles within the EU. The scope also included determining the barriers to the previously mentioned implementation.

3.2 The literature-gathering process

While searching for information and sources relative to the scope and aim of the study, a couple of databases were used. These scientific databases were *SCOPUS* and *Google Scholar*. To answer the research questions information was also gathered from the European Automobile Manufacturers Association (ACEA), the European Union official website. To perform better theory understanding and provide relevant information on the research subject beside of the scientific databases, an institutional homepage such as Federal Ministry for Economic Affairs and Climate action of Germany (BWK), The Federal Government of Germany (DB), World Resources Institute (WRI), the Swedish Energy Agency, The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) were used in the research. Additionally information's were gathered from DKV Mobility homepage that is a leading European B2B platform for on-the-road payment solution and Trans.Info a web site that provide news about the transport segment where all the authors are experts in the transport field such as Nabil Malouli a VP, Global Ecommerce lead DHL Supply Chain, Roberth Karlsson- logistics expert, Robert Hardy a Founder of the Customs Clearance Consortium, BREXIT advisor and Registered Expert with EU Commission and many more.

The initial search was conducted as a phrase search using the terms "electric vehicle", "electric vehicle charging", "charging infrastructure", "charging station", and "barriers for implementation of electric vehicles". The initial search yielded a total of 84,000 findings on Google Scholar and 76,390 findings on Scopus.

Based on the number of articles, a process of narrowing down was done using the built-in filtering functions in the various databases. On Scopus, articles and conference papers were selected as document types, English was chosen as the preferred language, and the range between 2015 and 2024 was defined. On Google Scholar, the Review articles between 2015 and 2024 were selected. This resulted in 44,547 findings on Google Scholar and 36,385 on Scopus.

To specifically explore charging infrastructure for commercial vehicles in the European Union and barriers to electric vehicles implementation, the search phrase was modified to "charging infrastructure" plus "commercial vehicle" and "barriers for implementation of electric vehicles." This yielded 136 articles on Scopus and 251 articles on Google Scholar. These numbers were good enough to proceed to the next phase.

3.3 Screening process

During the screening process, articles were assessed strictly to ensure relevance and quality. A summary of the literature collection process is presented in Table 1.

- **Duplicate removal:** Out of the total 387 articles, 125 duplicates were removed.
- **Abstract analysis:** Each article abstract was analyzed to determine its relevance to the research question. A total of 202 articles were excluded during this stage due to irrelevance.
- **Full-text analysis:** The remaining articles underwent full-text analysis to assess their suitability for inclusion in the review. Criteria for inclusion included relevance to electric truck vehicle charging infrastructure in the European Union and barriers to implementing electric trucks. The total number of articles excluded during this stage was 35.
- **Snowballing:** During the screening process snowballing was conducted to identify additional relevant articles from the reference lists of included studies. Five articles were identified through this process.

Table 1.

Literature collection process

Parameter			Result
	Scopus	Google scholar	
Number of retrieved literatures	136	251	387
Number of literatures duplicates			125
Number of literatures excluded from abstract analysis			202
Number of literatures excluded from full text analysis			35
“Snowballing articles”			5
Total literature			30

3.4 Quality assessment of sources

Certain criteria were determined to assess the quality of the sources gathered in the previous step. The criteria were:

1. Quality assessment based on peer review.

2. Quality assessment based on sample size and representativeness.

3. Quality assessment based on the authors.

The first criterion involved whether the chosen source had been peer-reviewed or not. This was deemed necessary since it meant that the peer review process had indeed validified whatever information the source contained. Articles that were not peer-reviewed were seen as a liability since they may not have been factually corrected the same way a peer-reviewed article might have been.

The second criterion that determined the quality was the sample size and representativeness. This plays a crucial role in determining the relevancy and robustness of the study findings.

The third criterion assessed who the authors of the sources were. Based on the instructions given by the University, no sources were to be used that were not scientific. It was also stated by the exact instructions that the authors of this report were to refrain from using sources that scientists or professors did not write. Hence, all articles written by bachelor, master, or PhD level students were excluded for usage in this study's writing process.

3.5 Data Extraction and Analysis

After collecting sufficient literature related to the research questions, the selection of the papers in the beginning was done separately by the two authors who maintained frequent communication but was noted that the data was still not specific. Then the authors started reviewing articles together based on the following criteria:

a. Content analysis focused on extracting data specifically for barriers and requirements for implementation of BET.

b. Time analysis explored the evolution of the BET barriers and requirements during the past ten years.

c. Geographic analysis focused on requirements for implementing BET within the EU and focused on barriers for implementing BET worldwide.

In the end, six articles focused on research question 1 were chosen and two articles focused on Research questions 2.

3.6 Selected literature and literature review

A summary of the selected literature is presented in Table 2, showing the year of publication, the research topic, the methodology, and their connection to related research questions.
In their article, Balke et al., (2024) presents a methodology for evaluating fast charging networks for BET in Germany, focusing on understanding the performance, robustness and crucial charging sites. Factors such as charging station locations, rest periods, vehicle parameters, and traffic distribution data are considered.

Deb et al., (2018), emphasize that challenges like underdeveloped infrastructure, optimal station placement, and charge scheduling prevent the EV's massive deployment.

Mareev & Sauer, (2018), explore the energy consumption and life cycle costs of overhead catenary trucks for long-haul transportation on German highways.

Mareev et al., (2018), investigate the challenges of using BET for long-haul transportation, primarily focused on required battery capacity and associated cost.

Qasim & Csiszár, (2021), aim to identify the main barriers for widespread adoption of BET in logistics. The research is based on a survey conducted among logistics professionals.

Table 2.

Summary of chosen literature

Authors	Year	Research Topic	Methodology	Research question
ACEA	2022	Infrastructure and investment requirement in EU for EV	Factual analysis	RQ1
Balke et al.	2024	Fast charging network for BET in Germany	Modeling & simulation	RQ1
Deb et al.	2018	Recent trends in charging infrastructure for EV	Modeling & simulation	RQ2
Mareev & Sauer	2018	Required battery capacity for long-haul transport in EU	Modeling & simulation	RQ1
Mareev et al.	2018	Energy consumptions of overhead catenary truck in Germany	Modeling & simulation	RQ1
Qasim & Csiszár	2021	Adoption of BET in logistics system	Interviews	RQ2
Speth et al.	2022	Fast charging network for BET in Germany	Modeling & simulation	RQ1
Shoman et al.	2023	Adoption of BET for long-haul transport in EU	Modeling & simulation	RQ1

Speth et al., (2022), developed a model for public high-power fast-charging infrastructure for BET in Germany.

Shoman et al., (2023), examines the charging requirement for BET in long-haul operation in Europa by 2030, considering truck driving regulation and different stop patterns offering valuable insights for charging infrastructure planning.

3.7 Limitation

Some limitations in this study need to be considered when evaluating the data. Firstly, it is possible that the search technique did not include relevant research, especially those published in languages other than English or those not included in the specified databases. Furthermore, incorporating inclusion criteria may have resulted in selection bias, as only studies that met the criteria were included. Moreover, the quality of the research included exhibited variation, potentially affecting the overall dependability of the findings. The broader applicability of the results may be restricted to the specific geographic setting that was examined in the research included.

4 RESULTS

In this chapter, the results of the research questions will be provided. The results show that various scientific authors have both points that they agreed upon and points that they diverge on. This chapter is divided into results for the first research question and then results for the second.

4.1 Requirements for the implementation of electric charging infrastructure and long haulage trucking

Based on the various articles analyzed, the following requirements were mentioned as needed for the implementation of electric trucks for long-haul transport.

Based on research conducted by (Mareev et al., 2018), several technical requirements were identified as needed for the implementation of long-haul electric trucks in the transport sector. Mareev et al., (2018) recognized the following requirements:

The first requirement was that the high energy consumption and battery capacity of lithium batteries need to be vastly improved to maintain long-haul transport. Mareev et al., (2018) argue that if the electric trucks themselves are not energy-efficient and do not have powerful batteries for long-distance transport, then the charging infrastructure requirements become obsolete. With improved battery capacity and energy efficiency of said batteries could, the amount of charging points be reduced and, at the same time, become more financially feasible (Mareev et al., 2018).

The second requirement recognized by Mareev et al., (2018) deals with payload restrictions of electric trucks. Mareev et al., (2018) argue that while electric trucks are 2.5 times more energy efficient than diesel trucks, they suffer in terms of payload. Mareev et al., (2018) give the example of an 825-kW battery for an electric truck reducing the truck's load capacity by 20 % less compared to fossil-fuel-driven trucks. It is thus required of the electric trucks to either compensate for the lack of space by being able to accommodate smaller batteries or by optimizing the entire truck by redesigning the structure to enable the support of a larger battery that minimizes the loss of loading space (Mareev et al., 2018).

In another article published (Mareev & Sauer, 2018), the same requirements mentioned above resurfaced, with the addition of the requirement for catenary charging infrastructure being the main charging infrastructure used. Mareev & Sauer, (2018) mention that due to the specific calculated energy consumption levels noticed during their study of electric road transport in Germany, the catenary charging type was seen as the most optimal one. The reason for this charging type being considered a requirement is that it may reduce the battery size and thus improve the payload restrictions of electric trucks (Mareev & Sauer, 2018). This charging solution also provides a stable power supply for the duration of the charge cycle, which may lead to improvements in battery power efficiency (Mareev & Sauer, 2018).

ACEA (2022) mentions in their master plan for European BET charging infrastructure that the main requirement for the implementation of efficient long-haul transport in Europe comes down to two points. The first point regards the charging infrastructure itself. In ACEA's master plan, it is mentioned that to sustain a highly operational fleet of electric trucks by 2030, there need to be approximately 279,000 charging stations spread across the entire European Union to meet the EU's regulatory GHG-emission targets for 2030 (ACEA, 2022). It is further mentioned that among these 279,000 charging stations, 84 % of them need to be located at fleet hubs, which means a charging station where multiple electric trucks can fast charge at the same time without having to wait in lines longer than two truck lengths (ACEA, 2022).

The second requirement point mentioned by ACEA (2022) goes into detail on charging speed technology. ACEA (2022) argues that a successful implementation of a large fleet of electric long-haul trucks must have as short charging times as possible when fast charging. For this to occur, ACEA (2022) suggests that Megawatt Charging Systems (MSC) should be built as a standard across the EU charging stations to avoid slower charging times and queue building at the charging stations. ACEA (2022), mentions that these charging stations would consist of chargers providing speeds of 700-800 kW and that this may become the industry standard by 2025. ACEA also argues that this requirement may also be able to reduce the number of chargers needed in the entire EU by 70 % due to better utilization rates and higher charging speeds (ACEA, 2022).

Speth et al., (2022) reinstate the previous point presented by both Mareev et al., (2018) as well as ACEA (2022) that an essential technical requirement for the implementation of long-haul electric trucking in Europe is epitomized by the need for energy efficiency. It is further claimed that said batteries need to be large enough to provide a long-range, while at the same time not reducing the truck payload by a factor larger than 20 % of the total loading capacity (Speth et al., 2022).

Another crucial technical requirement that Speth et al., (2022) mention is the inclusion of sufficient charging infrastructure points based on the predicted total number of electric trucks in Europe as discussed by ACEA (2022). Speth et al., (2022) further argue that based on the expected size of the future electric truck fleet, charging points need to be optimized with quick charging speeds to avoid long downtimes Speth et al., (2022).

The final requirement that (Speth et al., 2022) mention is one of a financial nature. Speth et al., (2022) propose that even though technical requirements are needed to produce charging infrastructure practically, there still needs to be enough financial aid behind said technological investments to enable them. Speth et al., (2022) further assert that financial aid and subsidizations from state and private equity sources are prerequisites to the technological requirements. The main financial requirement that has been noted regards lowering the lifecycle costs for all electric truck infrastructure (Speth et al., 2022). This includes the initial investment costs for both the electric truck purchase and the charging station assembly (Speth et al., 2022). The goal here is to reduce the lifecycle costs associated with electric trucks to be either lower than or at the very least on par with that of diesel trucks (Speth et al., 2022)

Just like previous authors have mentioned, Shoman et al., (2023) declare that the adoption of a widespread European electric infrastructure network only can be enabled by having adequate charging points. Shoman et al., (2023) do however stress the significance of diversifying the charging options. Shoman et al., (2023) propose that there needs to be a mixture of both slow and fast charging options to both support the entire fleet size but also to minimize any potential bottleneck effect that may arise at high-traffic routes and charging points.

Shoman et al., (2023) suggest that there needs to be 40,000 overnight charging stations to provide slow-charging options that can be timed with the end-of-shift times of the truck drivers. It is further suggested that 9,000 megawatt charging stations should be installed as well to provide fast charging options at various carefully considered geographic locations in Europe

Shoman et al., (2023). Based on these 49,000 potential future charging stations, Shoman et al., (2023) were able to predict a 15 % increase in the total market share for electric truck long-haulage within the transport sector (Shoman et al., 2023).

Balke et al., (2024), identify a multitude of pivotal requirements needed for the establishment of electric charging infrastructure in Europe. The requirements Balke et al., (2024) present fully concur with previous points of importance presented by previous authors. The first and main point that is being brought up regards the introduction of an extensive charging infrastructure with a high density of charging points (Balke et al., 2024). Balke et al., (2024) further elaborate that the lithium-ion batteries being developed ought to have higher energy density to be able to provide a longer range traveled per electric charge, which goes hand in hand with the requirement proposed by Mareev et al., (2018).

Balke et al., (2024) do however emphasize another crucial requirement, namely that of an integrated Energy Management System (EMS). These systems would be integrated into both the software systems of the electric trucks and the electric charging stations (Balke et al., 2024). These systems would manage and regulate the electric supply as well as the thermal levels to ensure that the charging is as effective as possible (Balke et al., 2024).

Balke et al., (2024) extend on the previous two points by also mentioning the optimization of the electric truck design itself. If the range of the electric truck is to be extended, then either larger-sized single batteries or a larger number of smaller batteries might be needed (Balke et al., 2024). As previously stated by both (Mareev et al., 2018) as well as Speth et al., (2022), these range-extending solutions may lead to a reduction of the truck's loading capacity by a factor larger than 20 %. Balke et al., (2024) thus suggest a solution to this potential suboptimization by redesigning the entire design of the truck to free up more loading capacity.

The final two requirements proposed by Balke et al., (2024) consider a slightly different approach. Balke et al., (2024) go on to mention that while the previous technical requirements are crucial, incentives also need to be provided in terms of financial support towards the hauler companies as well as the output of a centralized legal framework. The requirement of financial aid proposed by Balke et al., (2024) reverberates the previous points brought up by Speth et al., (2022) regarding government subsidizations for reducing the purchase and maintenance cost, as well as partial funding of the development, assembly, and maintenance of the charging station networks themselves (Balke et al., 2024).

The point regarding the legal framework would according to Balke et al., (2024) encompass the introduction of laws regulating safety performance standards of the trucks themselves, a standardized electric grid used in multiple countries, the introduction of environmental zones where emissions must meet specific levels and that all these efforts would be multinational Balke et al., (2024). Balke et al., (2024) further mention that while local and federal efforts within many countries may be low, the EU is emerging more and more as a leader in terms of cross-border standardizations and development of regulatory mechanisms with the *Fit for 55 initiatives* being a good example. These efforts of standardization and united regulatory mechanisms reflect the emission goals put forward by the EU in the *European Green Deal* initiative, effectively aiming at integrating these goals directly as benchmarks for the structural design and development of the charging stations and infrastructure (Balke et al., (2024).

4.2 Barriers to the adoption of electric trucks

Due to the long list of technological, financial, and legal requirements needed, it may come as no surprise that the triangularity of these efforts is bound to face some form of hindrance and/or adversity. Below is a walkthrough of a multitude of observed barriers that exist in the implementation of electric infrastructure for long-haulage transport.

According to research performed by Deb et al., (2018), the barriers to the implementation of electric charging infrastructure and further use of electric trucks are the following:

- Limitations in battery technology in terms of low energy output, uneven energy dispersion, and low thermal-cooling capabilities
- inadequate charging infrastructure in terms of the quantity and frequency of charging points
- A lack of public charging station variety, in terms of having a mixture of slow and fast charging options
- improper placement of charging stations regarding already existing infrastructure
- uncoordinated charging availability in the charging stations in terms of geographic proximity to motorways and the availability of dedicated charging spots for solely electric trucks

Qasim & Csiszár, (2021) divide the barriers for BETs into three different categories: technological, cost, and legal barriers. The technological barriers are the most extensive out of the three categories. Based on today's BET market, the barriers consist of:

- low battery capacity
- reduced range
- short lifespan of the batteries
- long recharging times
- complete or partial lack of charging stations for long-haul transport routes

According to Qasim & Csiszár, (2021), technological barriers are still seen as the most surmountable since the solutions to them are dependent on the ever-changing technological development, which is quite rampant right now within the given field. The other two groups of barriers are however seen as greater barriers (Qasim & Csiszár, 2021). The cost barriers consist of the fact that research points toward the total cost of ownership (TCO) being marginally the same for BETs compared to fossil-driven trucks (Qasim & Csiszár, 2021).

Although operational costs have been observed to be lower for BETs, the initial acquisition cost proves to be too high for many hauler companies to afford (Qasim & Csiszár, (2021). There are indications that lower-priced BETs may even cost as much as state-of-the-art fossil-driven trucks. In that case, Qasim & Csiszár, (2021) argue that hauler companies may be more inclined to buy the latter option for better operational performance in terms of longer range, and more robust engine output.

The final barrier category for BETs observed by Qasim & Csiszár, (2021) is the legal barrier category. Qasim & Csiszár, (2021) use the term “government support” to describe the legal barriers that exist. The study performed by Qasim & Csiszár, (2021) shows indications that hauler companies experience less than optimal support from their respective governments for the electrification transition. The hauler companies do not experience enough government subsidization to incentivize them into buying ETs over fossil-driven trucks, given the previous technological and cost-related barriers Qasim & Csiszár, (2021).

Due to these factors, a negative return on investment for the haulage companies acquiring electric long haulage trucks is not unlikely and thus becomes a liability that said companies may not be willing to take, especially in economically hard times with high inflation and interest rates (Qasim & Csiszár, 2021). The potential of dissatisfactory return on investment may also mean lower operational competitiveness, both in terms of delivery time and total cost of ownership for the haulage companies (Qasim & Csiszár, 2021).

5 DISCUSSION

The purpose of this study has been to evaluate and analyze the various requirements for the transition toward electric trucks used for long haul, and their belonging charging infrastructure. It has also been the purpose to evaluate what type of barriers exist that prevent or decelerate the transition for electric long-haul transport and the implementation of its charging infrastructure. The method used for writing this report has been a systematic literature overview. Based on the various types of methods suggested by Denscombe (2018), this method type stood out as the most suitable one. It was deemed most suitable based on various advantages in comparison to the other method types.

Denscombe (2018) claims that a project most suited for a systematic literature overview includes the following criteria:

1. A field of study that is narrow enough for the authors to be able to answer a very particular set of questions.

2. A field of study that has been extensively researched and where there is plenty of research to analyze.

3. A field of study where either the same type of method or a similar one has been used.

4. The research findings must be comparable and of a predominately qualitative nature.

Based on these criteria, it stood clear that the chosen field of study was suited for a systematic literature overview. As the information-gathering process began for the report's writing, all the aforementioned criteria could be found throughout the articles researched. However, the main reason for choosing this research method is its advantages. Denscombe (2018) argues that the advantages of choosing a literature overview analysis as a method type consist of the following:

1. They are systematic in their approach to finding accurate data. The authors are left with credible sources because of the rigorous vetting of this method's sources.

2. They are practical since they answer very specific questions based on a particular set of theory and thus provide coherency and impartiality.

Denscombe (2018) further mentions that there is only one main limitation to this method type: it works best on subjects that have been heavily researched before and from which there is a solid base of theory from which to extract information. Denscombe (2018) thus argues that this method type is not suitable for any field of study that is experimental or has not been widely or extensively researched. It is interesting to note, though, that this limitation does not limit the scope of this thesis since the field of research is established. Since this thesis sets out to answer two very specific questions about a particular subsection of a heavily researched field of study, can it be concluded that the authors could draw all the benefits of this method type without suffering from its sole limitation.

While this method type fits the thesis and its research very well, another type could also apply to this line of projects. Performing a survey with interviews of various researchers in the field could be a valid method type for researching any of the topics brought up in the seventh chapter of this thesis project. Performing a survey with interviews would work well, given that the topics in the seventh chapter are not heavily researched. They would not be suitable for a systematic literature overview.

The validity of this report has been carefully considered during the writing process. Given that a systematic literature overview narrows the research questions, any deviations from the theory and research questions could be avoided. The results yielded from the study are coherent with the field of study and thus provide linearity in the field of research. This report thus serves as a valid extension of previous research. While the field of study, related theory, results, and conclusion provide precise and specific answers to the research questions, the same procedure could be applied in a different setting or field of study and yield similar results based on the given theory of the other field of study.

As mentioned in the methods chapter, narrowing down the sources used occurred. However, it is important to notice that there were other tantamount sources that the authors chose not to include, even though they were reiterating the same theory and notions. It is plausible that this thesis could be recreated with other adequate sources on the topic and yield similar results after following the same method type.

Even though the various research papers used in the writing of this report include various authors, a level of consistency could still be upheld. By making sure that the authors had a similar academic background, that they were covering a similar narrow topic, and that they were basing at least part of their research on sources/data published in the last decade, the reliability of the results could be upheld by these measures of consistency.

5.1 The role of technology in society with consideration of environmental and ethical aspects

With regards to the environmental impact, can it be valued that the transition toward electric truck long haul transport and development of charging infrastructure may have environmental implications. As stated in the theory chapter, The EU and UN both consider the carbon emission levels of trucks to be a considerable environmental issue. The electric truck technology has the potential to reduce carbon emissions from the trucking industry which may improve the lives of EU citizens in terms of better air quality while at the same time lead to the EU reaching its goal of greenhouse gas reduction by 55 % by the year of 2030 (Lantz & Joelsson, 2023).

At the same time, ethical considerations need to be considered with these emission reductions. The various requirements and barriers available to the electric truck transition for long haul transport require an element of financial aid and stimulation to ease the transition. Not all EU-member countries may have the same options in providing financial aid to their local trucking and logistics companies in using new charging technologies (Fidanza ECR & Roman Haider, 2023). It is further important to note that to ensure a fair and widely dispersed technological improvement on the area, the EU may need to ensure that equal financial aid from the EU is given out to all of its member countries to ensure equal labor market impacts and developments (Fidanza ECR & Roman Haider, 2023).

5.2 Discussion of the charging requirements

After analyzing a wide array of sources on these requirements and barriers, the result shows that while the requirements may differ due to technological, legal, and financial developments over time, certain key points shine through as universally agreed-upon requirements. Two requirements are mentioned by all the studies included in this report, regardless of the publishing year. These requirements are:

1. Battery Technology: Even though the technology for lithium-ion batteries has developed since 2013, (which Mareev et al., (2018) draws its early data from) the latest article from Balke et al., (2024) which includes data from a full decade later, the key technological requirements remain. Mareev et al., (2018) reported that lithium-ion batteries needed to become more energy efficient and include better thermal cooling capabilities that either need to increase in size to enable higher energy output or increase in quantity for the same purpose. This is still at the expense of reducing the loading capacity of the truck, which from the earliest published source (Mareev et al., 2018) to the latest published source (Balke et al., 2024) remains a problem that has not been solved yet.

   It is interesting to note though, that Balke et al., (2024) point out a possible future solution to this size problem by redesigning the entire structural integrity of a conventional truck. This proposal suggested by Balke et al., (2024) may insinuate that the core issue at hand has been a fixed mindset of truck manufacturers and other transport industry stakeholders. It is further implied by Balke et al., (2024) that truck manufacturers may have been clinging onto the conventional design of a truck and attempted to reverse engineer the new electric batteries into them, instead of doing the opposite of customizing the rest of the truck's design around the battery's form factor.

2. Adequate Charging Infrastructure:
   It is mentioned in all of the six different studies analyzed that the development of a widely geographically dispersed, technically robust, and multi-faceted charging infrastructure is needed to promote the transition toward a larger electric fleet, as well as taking the already projected fleet growth into account (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022). All of the authors agree upon the principles that there needs to be a systematic deployment of charging stations with a certain amount of distance between them and that they are deployed at strategically important points where traffic volumes are high (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022).

   The authors also agree that the infrastructural deployments need to result in an alleviation of other high traffic infrastructure used by fossil driven vehicles by steering away the electric truck routes and creating entirely new routes with supported infrastructure solely for the electric trucks and their drivers (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022). Examples of such infrastructure include motorways, parking lots, motels, and gas stations (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022). All the authors also express the need for dedicated parking lots and spots where solely electric trucks can and will be charged

(ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022).

These parking spots dedicated to electric trucks would also include some form of accommodation for the drivers such as hotels and restaurants (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022). The authors also unanimously agree on the requirement of using multiple charging techniques in the infrastructural network, where both fast charging and overnight charging are available (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022).

3. The last point that is mentioned includes the use of trying to establish a standard for the minimum allowable megawatt charging rate, where all of the authors suggest that the higher the minimum standard, the better since it works a way of decreasing down times and avoiding potential bottlenecks (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022). This final point may suggest that the ambition has always been to ensure that the charging time is as fast as possible, even during the “slower charging” options.

Even though it might be reassuring that the authors have come to some form of consensus regarding certain requirements, the points of divergence do need to be addressed. As technology has steadily developed over the years, a shift in focus can be witnessed regarding what is seen as technically important. Even though the previously agreed-upon requirements are technical in nature, the finer details of them have changed. (Mareev & Sauer, 2018) suggested that the integration of catenary systems is very important, a point which none of the other authors discuss at all or only mention very briefly.

While Mareev & Sauer (2018) suggest that the minimum charging rate should be as high as possible to avoid long downtimes, a few of the other authors suggest (ACEA, Shoman and Balke) that this charging rate should be in the megawatt range. It is then plausible to question why the Mareev & Sauer (2018) did not mention this limit specifically. The lack of mention might have been due to a lack of technological development regarding the batteries themselves or the chargers, or that it was merely seen as unfeasible or unnecessary, and that the lower limits would suffice at the time of research for Mareev & Sauer (2018).

It is also clear that the earlier published articles (Mareev et al., 2018; Mareev & Sauer, 2018) are a lot more fixated on the technical requirements and almost solely discuss these, whereas the later published articles, more specifically (Balke et al., 2024; Shoman et al., 2023) also consider financial and legal dimensions. The latest article from 2024 by Balke et al., (2024) even suggests that the importance of the financial and legal dimensions surpasses that of the technical dimensions for the transition and implementation of electric long-haulage and its charging infrastructure. A clear example of this is how the two latest articles (Shoman et al., 2023; Balke et al., (2024) specifically mention the use of lifecycle cost comparisons that includes acquisition, maintenance, and fuel costs. Previous articles (Mareev et al., 2018; Mareev & Sauer, 2018; Speth et al., 2022) do not mention this dimension. This might be since not many electric trucks were deployed at the time of writing for the older articles, and hence a lack of data from the hauler companies themselves describing their satisfaction with the trucks and how they affected their finances.

5.3 Discussion of the barriers

Regarding the barriers of the electric truck transition and infrastructure development, a similar theme can be observed compared to the previous part. The different authors (Deb et al., 2018; Qasim & Csiszár, 2021) do agree on certain barriers being true despite the difference in publishing year and the developments of technology. The main barrier that both author groups agree on regards the lack of current charging infrastructure. Both author groups argue that any further research on the topic of charging infrastructure must assessed with caution, since their arguments are based on theoretical charging networks, as opposed to existing ones. This is a very interesting point, since both (Deb et al., 2018) and Qasim & Csiszár, 2021) hence imply that before actual charging networks have been established, the effectiveness of them cannot be accurately prognosticated.

The author groups (Deb et al., 2018; Qasim & Csiszár, 2021) both agree that the technical barrier of the infrastructure deployment cannot be addressed before the financial barriers have been resolved. Both author groups agree that the financial barriers include a lack of support, funding, and subsidization from both federal governments and the private sector. Another dimension of the financial barriers that both author groups agree upon regards the costs of acquisition, ownership, and maintenance for electric trucks, where access to ownership of electric trucks is seen as having a financial barrier of entry (Deb et al., 2018; Qasim & Csiszár, 2021).

However, that is the extent of which the author groups agree with each other. Even within their first point of agreement, dissidents appear. While Qasim & Csiszár, (2021) argue that the overarching lack of charging infrastructure is an issue, Deb et al., (2018) propose that simply introducing charging infrastructure en masse will not remove the barrier. Deb et al argue that the introduction of charging infrastructure must be diligently planned with all the previous aspects mentioned by the requirement authors above for it to be effective. Deb et al., (2018) even argue that hastily introducing charging infrastructure without careful planning may result in infrastructural disturbances that may negatively impact other traffic flows as well.

Another point of discrepancy between the author groups revolves around the legal barriers. Qasim & Csiszár, (2021) were the ones who introduced the three-dimensional concept of barriers, consisting of a technical, legal, and financial dimension. Based on this model and the research conducted, Qasim & Csiszár, (2021) argue that the legal barrier acts as the main barrier. Qasim & Csiszár, (2021) further argue that if the legal barriers are not resolved, then the other two dimensions cannot be addressed, and the electric truck transition cannot be realized. Deb et al., (2018) do not focus on the legal barriers at all. This is in line with the previous points of divergence among the requirement authors, where the latest author, Balke et al., (2024) was the only one discussing the legal dimension of it all. Regarding the barriers, Qasim & Csiszár, (2021) argue for the legal dimension, while the older article of Deb et al., (2018) does not. A theory as to why that may have to do with the fact that as the years progress, societies move closer toward the deadlines for many of the environmental agreements. As time draws nearer, the subject of legally enforcing change may be seen as the only effective measure to change the way hauler companies and truck manufacturers act.

The final point of discrepancy between the two author groups regards the financial dimension. The later report (Qasim & Csiszár, 2021) considers the global economic recession and inflation since that report was written during the pandemic. The previous report by (Deb et al., 2018) focuses on general financial issues, such as the need to look at the total costs of ownership and the return on investment.

The overall impression that is emerging after comparing and analyzing the results of the six studies (ACEA, 2022; Balke et al., 2024; Mareev et al., 2018; Mareev & Sauer, 2018; Shoman et al., 2023; Speth et al., 2022) may suggest that the earlier published studies did (Mareev et al., 2018) and (Mareev & Sauer, 2018) not treat electric long haulage as a realistic subject, but instead as something very speculative without much actual physical data on it. It is also clear that as time has moved on, this speculative nature of it all has transformed into firstly actual belief into this becoming a reality seen in (ACEA, 2022; Speth et al., 2022), and in the latest published articles (ACEA, 2022; Speth et al., 2022) this being a reality, though small scale, in Europe, and that the aim of the later articles no longer is to prove whether it's possible or not but to scale up now as much as possible, and more importantly, whether the scale-up is possible, or if this small scale usage and production is where things cap off.

In terms of barriers, can it be said that these barriers reflect the development of the various requirements over the years, it was a bit surprising how important the legal dimension appears to have become over the years and that the legality of the electric truck transition and charging infrastructure deployment trumps even the technological advancements of the field and the financial aids and capital being invested into development and deployment of charging infrastructure.

It was also interesting to observe how the global economy affects this topic of barriers. The economic impacts the pandemic had globally also had to be considered when discussing the deployment of charging infrastructure and electric truck acquisition in the latter report by Qasim & Csiszár, (2021). At the same time, Deb et al., (2018) cannot be held responsible for not discussing this topic further, since the economic implications of the pandemic were unforeseeable at the time of writing that report.

6 CONCLUSION

This systematic literature overview has overseen the potential for electrified long-haul transport within Europe. The report aimed to determine the requirements and barriers for said transition, including deploying the charging infrastructure needed to support the transition. The report has concluded that the potential for actualizing this transition is great and that the requirements are multifaceted.

The report determined that both the requirements and barriers for the electrification of long-haul transport in Europe must be divided into different sub-groups. These groups include a technical, financial, and legal subgroup, comprising the core of what is needed in terms of developments and what issues need to be resolved before the physical manifestation of an electric long-haul network across the European continent emerges.

Although including research from multiple authors, written in different years, specific key points were vitally important requirements unilaterally amongst the various authors. One of these critical requirements includes deploying advanced charging infrastructure networks that offer multiple charging options. These options include the complete list posted in the theory of the report, such as fast charging, overnight charging, wireless charging, and dedicated areas for parking and resting solely for the electric trucks and their drivers.

Another conclusion that the report can draw regards the financial and legal dimensions of this transition towards electric long-haul transport. Based on the legislative developments of the European Union and research from some of the more recently published studies, the legal dimension of the electrification progress stands as its most vital requirement and barrier. Legislative measures from a border-crossing entity such as the EU have the real power to impose actual change. Where the EU goes, its member states follow in terms of legislative developments. It also stands clear that the EU has the monetary resources to encourage its member states and provide financial support directly in helping produce charging networks and subsidizing the acquisitions of electric trucks for long-haul use.

However, it also stands clear that even if all the legislation becomes deployed and financial measures are taken to help the transition, the technology of today’s electric trucks and the lithium-ion batteries used have their limitations. The report can conclude that although it is technically possible for current-generation lithium-ion batteries to perform long-haul transports, they need to be technically approved to ease the transition and become more reliable regarding travel range and technical robustness.

To conclude, the road towards electrification of European long-haul transport is yet to be actualized. However, great potential is observed, and if the various technical, financial, and legal requirements are met sooner rather than later, then the goals set up by the EU and UN for a fossil-free Europe may become feasible, given that the barriers to the transition are also solved. If anything, this report shows that the road to a fossil-free transport sector does not come down to single factors, such as technological developments, but requires a mobilization of all sectors of European society to become a reality.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

The list of recommendations for further research is extensive. Although this field of study has been researched for well over a decade, the results of this report suggest that the actual transition towards electrification is starting to occur at the time of the writing of this report (2023-2024). Based on the research conducted for this report, many possible solutions to the barriers reviewed may emerge in the future. Such solutions may include the use of solid-state batteries, the use of battery swapping, and the use of hydrogen-fueled trucks instead of/or as a complement to electric ones. Regarding the various requirements needed, it would be interesting to perform a study that goes explicitly through the logistics behind providing enough electric grid capacity to support the electric truck infrastructure from an engineering point of view.

Another interesting idea for a future project involves the effect ts of the electrification of long-haul transport on the social sustainability of hauler companies and trucking occupations. A final recommendation for future research involves the environmental impact of long-haul transport electrification on emission levels. Such research could be interesting to look at in a decade or two, when the deployment of the charging infrastructure has been actualized and emission data has started to emerge.

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