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Circular Supply Chains Through Standardisation of Heavy-Duty Electric Truck Batteries

Master's thesis in Supply Chain Management

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Summary

To reduce the adverse environmental impact of transportation, there is a need to develop electrical vehicles. The automotive industry faces a huge challenge in managing batteries after they have reached their end of life in the vehicles. Furthermore, the materials used in batteries are critical, making it crucial to find solutions on how to extend the life of the batteries as well as reducing the need for virgin materials. Currently, different vehicle manufacturers produce brand-specific batteries, resulting in a large variety of batteries on the market. This variety causes problems when it comes to finding solutions on how to reuse, repurpose and recycle batteries effectively. One solution to handle these problems could be a global standardisation of the batteries, which has been successful for consumer batteries.

This study was performed together with a truck manufacturer, thus the context for the thesis has been on heavy-duty electric truck batteries. The aim of the study has been to investigate how the standardisation of heavy-duty electric truck batteries could reduce the variety of batteries and what circular supply chain is most appropriate for the context. To reach the aim of the study, an inductive approach was used. The main method used for data collection was workshops, which were analysed through a thematic analysis.

The findings show that there exist 22 problems related to the large variety of batteries on the market, for different actors in the value chain. Furthermore, it has been seen that the problems could be managed by an implementation of a standard for the batteries. However, the study also shows that it is of importance to consider all different perspectives when designing and implementing the standard, since there are different opportunities and challenges for the different actors. Finally, to create circular supply chains it is possible to use a closed-loop or an open-loop setup, where open-loop is preferrable to reach the full potential of battery standardisation and gain environmental benefits.

Keywords: *circular economy, battery supply chain, electric vehicles, standardisation, reverse logistics, electric vehicle battery, lithium-ion battery, recycling, circular supply chain*.

Acknowledgement

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List of Acronyms

List of acronyms that are used in this master thesis below. The list is in alphabetical order:

CE	Circular Economy
CLSC	Closed-Loop Supply Chain
CSC	Circular Supply Chains
EOL	End-of-Life
EV	Electric Vehicle
EVB	Electric Vehicle Battery
LIB	Lithium-Ion Battery
OLSC	Open-Loop Supply Chain
RSC	Reversed Supply Chain
SC	Supply Chain

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1. Introduction

The chapter begins with a background on the transition from linear economy to circular economy and the electrification of heavy-duty trucks. Thereafter the project's aim and research questions are described and presented. Lastly, the delimitation of the project is brought up.

1.1 Background

The importance of sustainability has increased in the past years as environmental issues have been in rapid growth. It is urgent that companies and industries take action to solve the environmental problems, by for example reducing the amount of greenhouse gases. The transportation sector represents about 25% of the European Union's (EU) greenhouse gas emissions, where emissions from heavy-duty vehicles in road transport are significant (European Environment Agency, 2023). To reduce the environmental problems in the transportation sector, governments and unions have implemented regulations and policies. In 2019 the EU presented an emission performance regulation targeting the production of new heavy-duty vehicles to further incentive zero-emission vehicles (European Parliament and Council, 2019).

To reach a zero-emission transportation system, there is a need to speed up the development of electrical trucks (Nåbo et al., 2024). The development requires a major societal transformation, where companies within the transportation system need to renew their knowledge and adapt to the benefit of society. The focal firm in this thesis project is one of the market-leading manufacturers of heavy-duty trucks. The Case Company has during the recent years introduced several electric trucks in their line-up.

The electrification of heavy-duty trucks faces not only technical challenges but also the fact that transportation systems are global networks (Nåbo et al., 2024). Vehicles travel in regions and across national boundaries, thus electric truck solutions must be viable in multiple countries at once. When the truck batteries reach their end-of-life (EOL), they must be collected to enable, for instance, recycling (Tankou et al., 2023). The EU introduced the *2030 EU Battery regulation* to create a circular economy for vehicle batteries by ensuring that raw materials in batteries are collected, reused, and recycled (European Parliament & Council, 2023).

The electrification of the automotive industry results in an industry transforming from a fuel-intensive system to a more material-intensive one. In line with the transition to electric vehicles (EVs), the need for materials to produce lithium-ion batteries (LIBs) is increasing (Dunn et al., 2021). The material used in the production of electric vehicle batteries (EVBs) contains critical materials, such as cobalt, lithium, and nickel. These metals has a risk of meeting short supply in the future, which in turn could be a barrier to the wide use of electrified trucks (Ahuja et al., 2020). Moreover, the extraction of the needed metals has both ethical and environmental issues, which highlights the importance of transforming the linear economy, into a circular economy (Ahuja et al., 2020). The mission of the circular economy is to reduce the waste of materials, systems, and products by designing optimal social, economic, and environmental values through a product's entire lifecycle (Velenturf & Purnell, 2021).

The estimated number of batteries reaching their EOL is increasing. Approximately 1.2 million heavy- and light-duty vehicle batteries, globally, will reach EOL in 2030, and in the year 2050, this number is estimated to reach 50 million (Tankou et al., 2023). Therefore, the need to create a system supporting the second-use and recycling of electric vehicle batteries is crucial. Giving the truck batteries a second-life is possible since they still contain a lot of capacity after their first use (Ahuja et al., 2020). One possible repurpose application is energy storage. Energy shortage is one of the biggest risks that has been identified by the World Economic Forum (World Economic Forum, 2024). However, the heterogeneity of battery varieties constitutes a challenge to the scalability of energy storage systems (Dominish et al., 2021). The number of battery varieties is expected to increase as technology for battery performance improves (Kotak et al., 2021).

Recycling of batteries occurs when reuse is not possible anymore or when the health of the battery is too poor to reuse. Today it is technically possible for around 90% of the components in a battery to be efficiently recycled, and 95% of critical metals in batteries can be recovered for reuse (Northvolt, 2021). However, the recycling process of lithium will only be performed if the value of the recovered material outweighs the cost of the recycling process (Dunn et al., 2021). The economic infeasibility is a key reason why batteries today not are recycled to a large extent. Furthermore, the recycling process must enable international battery collection and include different stakeholders that can manage the recovered material from the different components.

To comply with stringent regulations and to reach a zero-emission transportation system, companies must renew their value proposition. Different solutions have been identified as important to develop the electric transport system, and one of them is standardisation (Tankou et al., 2023). A global standardisation of EVB and its design can reduce a number of problems like access to battery content information, and process automatization with safety improvements and cost reductions. (Tankou et al., 2023). An example of a successful global battery standardisation is the consumer batteries (Larsson & Ståhl, 2012). The reason for the consumer battery standardisation was manifold, it harmonised product quality, ensured interchangeability among the different producers, reduced the different battery varieties, and provided safety guidelines (Linden & Reddy, 2002). Furthermore, the standardisation of consumer batteries allowed the application market to grow.

1.2 Problem Specification

With the automotive industry's transition to electrification, lies the challenge of the material-intensive value chain. The volume of heavy-duty electric trucks is anticipated to increase rapidly, making the management of their batteries a key question with regard to sustainability. Today different truck manufacturers develop brand-specific electric batteries, resulting in a battery variety in the market. To reduce the negative environmental and social impact, it is crucial that the batteries can be reused, repurposed, and recycled properly, which is difficult today with the amount of variety. The background presented four of the main problems that different stakeholders (such as recycling actors and the truck manufacturers), in the value chain are facing today which are:

- Energy supply risks
- Supply of critical resources
- Battery variety in the market
- Reusing and recycling batteries

With regards to these challenges, there is a need for a different approach to manage the development of electric trucks. Consumer batteries have, as stated before, successfully become a global standard. The development of a global standard for heavy-duty truck batteries could reap similar benefits as consumer batteries, thus helping the modern automotive industry in the transition to a circular supply chain.

1.3 Aim

The aim of this study is to understand what problems arise as a consequence of the truck battery variety in the market. Furthermore, it will focus on how the standard should be designed to bring the most benefits for all key stakeholders in a battery value chain. The study will also investigate how the standardisation of heavy-duty electric truck batteries could contribute to a more sustainable and circular supply chain. Furthermore, the prerequisites which are needed to enable a global standardisation of heavy-duty electric truck batteries will be identified, since they are necessary to understand if a standard would be possible to implement.

1.4 Research Questions

In the market today, all automotive manufacturers develop and produce batteries for their specific brands. This might not be surprising given that companies have used the new area to gain competitive advantages and market shares (Dominish et al., 2021). Furthermore, since the development is ongoing every manufacturer has several generations of their batteries. As presented in the background, there are several problems connected to the variety of manufactured batteries: reuse applications, the recycling process and interoperability problems. As a consequence, the battery supply chain has not yet fully been able to transform from a linear chain into a circular one. According to several scholars, there is a need for a unified solution to develop and transform the transport system (Tankou et al., 2023; Nåbo et al., 2024; Ahuja et al., 2020). A viable option could be the introduction of battery standardisation. To fully understand how standardisation could help to solve the problems that are arising as a consequence of the variety, it is important to first get a grasp of the extent of current problems in the supply chain, from the production of batteries to recycling. Thus, the formulation of the first research question:

1. What type of circular value chain problems arise today due to heavy-duty electric truck battery variety?

Standardisation of batteries has been pointed out as a potential solution to the battery variety problems (Tankou et al., 2023). Even though standardisation could be a possible solution, it is crucial to understand what opportunities it would bring, how it solves the current problems and what challenges it could create in the supply chain. Standardisation is an all-encompassing subject and in a battery context there are several levels which can be standardised. Thus, it is important to understand what choice of standardisation level in the battery will bring the most opportunities and handle the identified problems. Furthermore, it is important to ensure that the opportunities are beneficial for all key stakeholders in a circular battery value chain: OEMs, OEMs' customers, second-use actors, and recycling actors. These stakeholders have been pointed out as key actors since they represent the manufacturer of the electric vehicle, the first user of the batteries, the second user of the batteries and the recycling of batteries to restart the material flow. The focus needs to be broader than just on the manufacturing company since environmental concerns are important to manage. The following research question is formulated as:

2. Managing variety: a) How does standardisation address the identified variety problems and b) What battery level should be standardised to bring opportunities for all key stakeholders?

In recent research, the concept of circular supply chains has developed as a response to the transition to circular economy practices (Lahane et al., 2020). Within circular supply chains, open-loop supply chains (OLSC) and closed-loop supply chains (CLSC) have become popular ways to describe different ends of the same spectrum. Currently, there is a lot of literature on the application of CLSC in different industries, while OLSC has not yet reached this level. The two different circular supply chain setups have different characteristics, and it is important to understand how these fits in a given context. Furthermore, the creation of circular supply chains can affect all key stakeholders in different ways, thus it is important to consider as well. With this in mind, the formulation of the third research question:

3. What circular supply chain structure for heavy-duty electric truck batteries would be more appropriate to achieve benefits for all key stakeholders?

1.5 Delimitation

Since the thesis project is conducted with a time restriction, some aspects of the subject must be limited. In the literature, trucks are included in the category of heavy-duty vehicles, but so do buses and construction vehicles. Since the partner of the thesis project is a truck manufacturer, only the context of standardisation for truck batteries will be considered. However, the findings of the report could apply to other heavy-duty vehicles as well. The aim is to explore the concept of standardisation in the truck battery supply chain, thus highlighting implications on a general level rather than in-depth of specific parts of the supply chain. Therefore, the identified problems, possibilities of creating circularity or the standardisation prerequisites are not to be perceived as an exhaustive list, but rather a way to create understanding and indicate what areas might be of interest. Since the thesis project partner is a truck manufacturer, the perspective of a manufacturer will naturally be part of the report, thus limiting the perspective of other actors.

2. Literature Review

In this chapter, the literature regarding the thesis topic will be brought up. The literature consists of four main areas, which are illustrated in Figure 1 below. First, the structure of electric vehicle batteries is described, followed by the foundation of the circular economy and its supply chain consequences. The variety in a battery context is highlighted in the third part of this chapter. The fourth and last part of the chapter includes standardisation, problems with the absence and the requirements to be able to implement a standard.

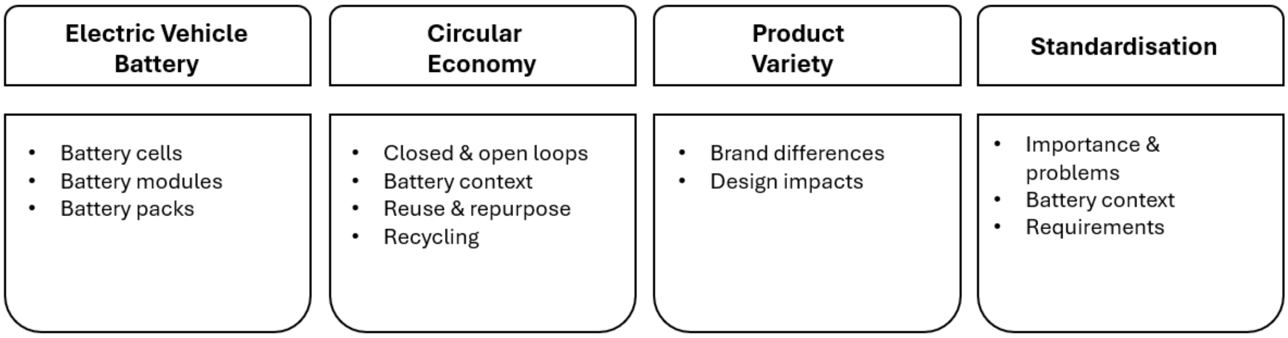

Figure 1. Illustration of the Different Parts in the Literature Review

The way these topics relate to each other is illustrated in Figure 2. The left circle encapsulates the current challenges facing the automotive industry. The right circle includes potential solutions for managing product variety and achieving sustainability. In essence, the union of the two circles represent the focus on overcoming and managing today's challenges with battery variety from a supply chain perspective in the automotive industry.

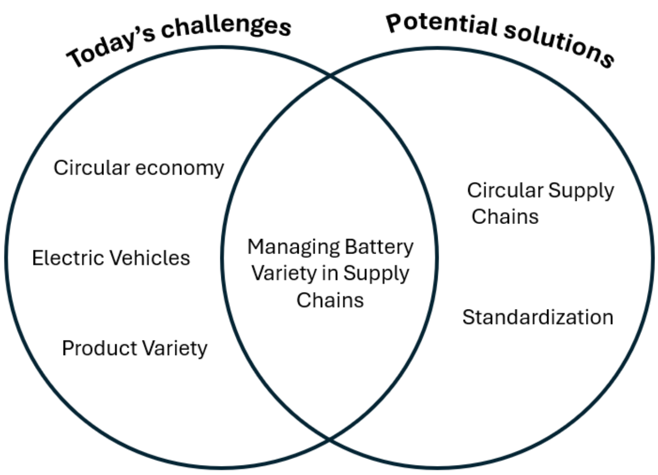

Figure 2. Venn Diagram of Theory

2.1 Electric Vehicle Batteries

Lithium-ion batteries are currently the most widely used batteries on the market for the automotive industry and stationary energy storage (Duffner et al., 2021). The reason for increased usage of LIBs is because they have higher energy density than previous variants of batteries, which in turn increases the driving range of EVs that use these batteries (Duffner et al., 2021). Another advantage of LIBs is that they have a high power capacity, which applies both to charging the battery but also to discharging (O'Leary, 2022). Therefore, when a LIB is used in a frequently driven truck in combination with the need for a lot of power, high energy density and high-power capacity must be able to be balanced effectively. However, there is a need to continue to develop the battery to increase the lifespan, range, and reduce the cost of manufacturing the batteries (Liu et al., 2022).

Traditional batteries in EVs up to date consist of a cell-module-pack structure. The core part and the smallest unit in all electric vehicle batteries is the battery cell. Several cells are then combined in a battery module and a set of battery modules then comprise the battery pack, together with management systems (Yu et al., 2023). Several packs can then be installed into the electric vehicle and the total unit including all packs is known as a battery system (Yu et al., 2023). In this study, the main focus will be on the cell, module and pack levels. An illustration of the battery structure can be seen in Figure 3. It is hard to create batteries for a heavy-duty electric truck since the requirements for the driving range are high and need to be equal to the diesel trucks (Nykvist & Olsson, 2021). Furthermore, the size of the battery is determined based on the energy usage and requirements of driving range between recharging. Longer driving ranges between recharging means that a battery in an electric truck must be larger and heavier to be able to include a high energy level.

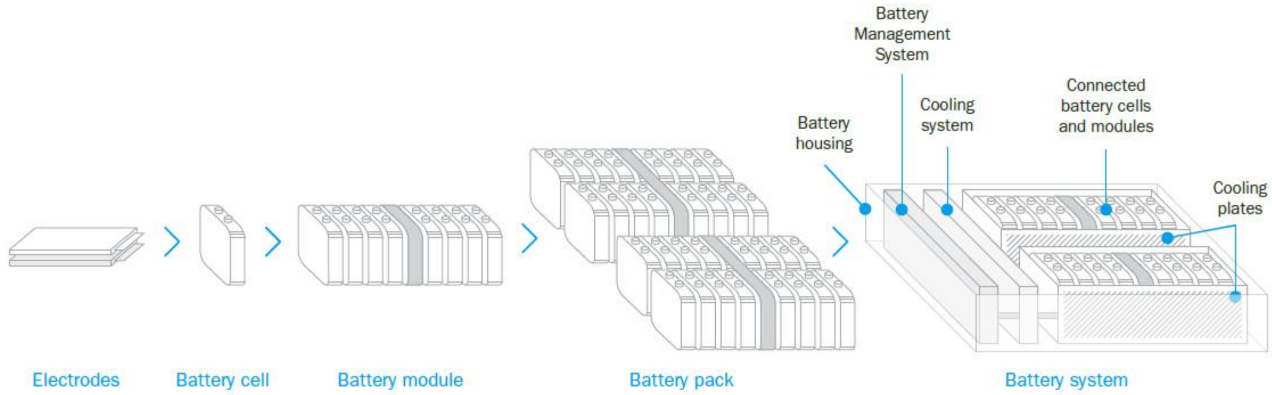

Figure 3. Breakdown of a Battery Structure (Outokumpu, n.d.)

2.1.1 Battery Cells

A battery cell contains electrodes (an anode and a cathode) and a separator in an electrolyte (Windisch-Kern et al., 2022; Young et al., 2013). *The battery cell is the smallest unit in the structure of an electric vehicle battery and converts chemical energy to electrical energy.* There are three main casings for the battery cell's components and electrochemistry: cylindrical, pouch and prismatic (Baazouzi et al., 2023). The different battery cell formats can be seen in Figure 4. Considering the whole battery cell market for electric vehicles in 2021, prismatic cells had the highest share with about 25%, pouch cells made up approximately 20% and cylindrical cells 15%, the rest of the market constituted of ambiguous cell formats (Link et al., 2023). Stakeholders in the automotive industry have pointed out standardised cell sizes as an important factor in achieving economies of scale (Link et al., 2023).

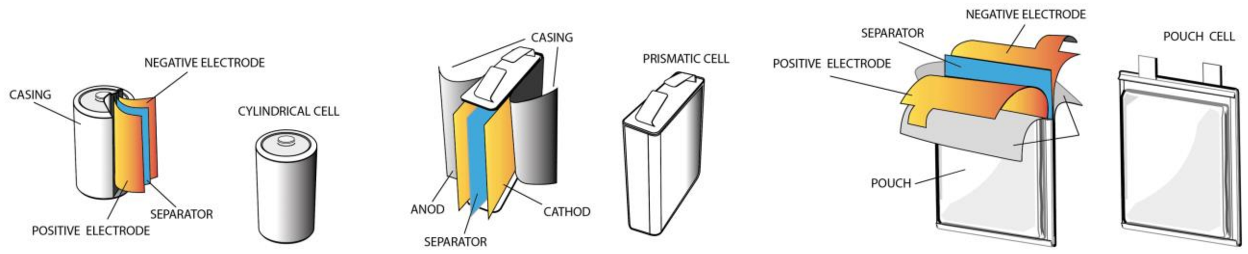

Figure 4. Illustration of Different Cell Format Types. Adapted from (Ma, n.d.)

In this level of the battery structure, there is a large amount of variety due to the cells utilising different electrochemistry. The reason for developing different electrochemistry is because the batteries are usually developed in connection to the need of the application and because different chemistries give batteries different characteristics (Aphale et al., 2020). Additionally, developers can change what materials are used for the cathode to gain another factor to change battery characteristics (Aphale et al., 2020). The reason for experimenting with different electrochemistry and materials is to achieve a desirable balance between costs, performance, and safety (Ding et al., 2019). Since EVBs are relatively new on the market, there is a need to experiment with electrochemistry to get a competitive advantage and balance the aforementioned product characteristics (Ahuja et al., 2020). As mentioned earlier in the chapter, LIBs are the most used technology in the automotive industry. Lithium-ion technology is a group of different lithium-based electrochemistry and not a single technology in itself (Ahuja et al., 2020; Young et al., 2013). The main way of differentiating different varieties of lithium batteries is based on the material for the cathode and anode (Ding et al., 2019; Windisch-Kern et al., 2022). The materials used for the cathode and anode are commonly lithium, cobalt, manganese, graphite, and nickel (Backhaus, 2021). However, with consideration of cost, capacity and social sustainability, cobalt content in batteries is expected to decrease and be replaced with other materials like nickel (X. Ma et al., 2021).

2.1.2 Battery Modules

The next level in the battery structure is the *battery module which contains a set of cells* (Young et al., 2013). Within the battery module, the battery cells are arranged and connected in series, in parallel or a combination of both (Windisch-Kern et al., 2022). The combination of cells in series and parallel determines the voltage of the module, and in extension the battery pack (Batsche & Hoerman, 2022). The size, shape and structure of the battery module depends on which format the battery cell has. There is currently no standardised design for this level in the battery structure (Gerlitz et al., 2021). The battery module housing is important because it acts as a protection for the battery cells from dust, moisture and water which causes degradation (Gerlitz et al., 2021). Thus, the lifetime of the battery module and its function can be intact as long as possible. Although the battery module design varies, there are six components which are included in all modules regardless of cell format: battery cell, cell contactor (to transmit electricity), cell fixation (structure of cells), Battery Management System (BMS), cooling system and housing (Gerlitz et al., 2021).

The BMS is a control unit which helps protect the battery from too rapid degradation and ensures that the battery is operating optimally (Pistoia, 2009). It does so by controlling and monitoring the activities in the battery to make sure that the currents, voltage and temperature of the individual battery cells are within a safe operating window (Gerlitz et al., 2021). Moreover, the BMS calculates the battery's state of change as well as its state of health, which are important factors in evaluating the quality of the battery (Gerlitz et al., 2021).

2.1.3 Battery Pack

The battery pack houses several battery modules in a single container (Young et al., 2013). The final design of the battery pack depends on several factors, what battery cell has been used, what the architecture of the vehicle looks like and what performance is required from the pack (Engel et al., 2019; Warner, 2014). The architecture of an electric vehicle and its battery depends on whether the vehicle is designed from scratch to use batteries or if it is retrofitted to use batteries (Warner, 2014). The components within the battery pack aside from the battery modules are management modules and accessories like cooling systems, connecting cables and a BMS (Yu et al., 2023).

As with the previous levels in the battery structure, battery pack design is not standardised nor has a few dominant designs in terms of size and shape appeared. Currently, battery packs have different design trends, in which the design moves away from the traditional cell-module-pack structure, for example removing the module (Pampel et al., 2022). Manufacturers and battery designers are constantly looking for innovative ways to increase the energy output while reducing the weight and size of the battery (Warner, 2014). A larger battery might mean a longer driving range, however, at the same time, battery weight means that less load can be carried on the vehicle. Furthermore, a larger battery entails a greater cost, which will increase the price for the vehicle.

2.2 Circular Economy

As the environmental issues are increasing, organisations want to ensure that their supply chains are sustainable from an environmental, social, and economic perspective (Lahane et al., 2020). To do so, the linear economy model is not enough. Several authors mention that circular economy (CE) can be seen as a pathway to sustainability (Velenturf & Purnell, 2021; Kirchherr et al., 2017; Poldner, 2021). Despite that, there is no common definition of the CE concept. However, the definitions provided by different authors have one view in common, CE is aiming at improving the use of resources (Velenturf & Purnell, 2021). The idea of CE is to ensure efficient resource usage and minimise waste, thereby promoting more sustainable production and consumption by closing the loop of material as well as resources (Berlin et al., 2022).

The mission of CE is to reduce the waste of materials, systems, and products by designing optimal social, economic, and environmental values throughout a product's entire lifecycle (Velenturf & Purnell, 2021). The definition of CE provided by the Ellen MacArthur Foundation is the most widely used among the different authors. Circular economy is, according to the Ellen MacArthur Foundation *"an industrial economy that is restorative or regenerative by intention and design*" (2023, p.7).

The concept of CE has developed into circular supply chains (CSC) to involve the management of the supply chain of the CE (Lahane et al., 2020). When addressing CSC, several aspects need to be taken into account, such as CSC collaborations, reverse logistics, closed-loop supply chains and producer responsibility (Lahane et al., 2020).

2.2.1 Open and Closed-Loop Structures

One part of CE is the *reversed supply chain (RSC), which can be divided into closed-loop and open-loop systems* (Berlin et al., 2022; Kabir et al., 2021) *In the closed-loop system, the products are, after use, returned to their original supply chain to recover value* (Govindan et al., 2015). The return is done by the manufacturing company to be able to, for example, recycle the products. To ease the return and make it possible, a manufacturer could use retailers to collect the products from the customers (Kabir et al., 2021). An example of a closed-loop supply chain (CLSC) is Coca-Cola's universal bottle, which is a reusable bottle for their different brands (Sudusinghe et al., 2024). The recovery focus is the bottle, and this is achieved by support from Coca-Cola partners who wash and refill the bottles once more. In general, there is limited ability to recover value from the product in a CLSC since the reversed process does not involve a lot of other actors in the chain (Farooque et al., 2019).

The CLSC will help organisations to benefit from an environmental, economic, and social point of view (MahmoumGonbadi et al., 2021). Nevertheless, the focus of the CLSC is to optimise the financial parts of the organisation, and therefore the concept has been questioned as to whether it is sustainable by its definition (Kalverkamp & Young, 2019). Implementing a CLSC requires large investments for the organisation itself since all the investments need to be within the organisation (MahmoumGonbadi et al., 2021). This means that the organisation needs to invest in facilities that are going to both collect and reprocess their products after they have reached their EOL. However, CLSC is considered to be a suitable solution when it comes to collecting and reusing dangerous EOL products (Tavana et al., 2022). An illustration of the fundamental logic of a CLSC can be seen in Figure 5.

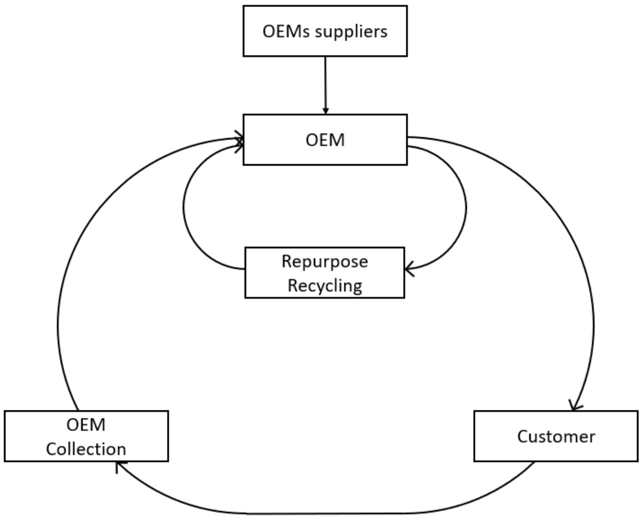

Figure 5. Illustration of a Closed-Loop Supply Chain

In the open-loop, the focus is not on the product recovery but instead on the recovery of components and materials (Berlin et al., 2022). In the open-loop supply chain (OLSC), the products that are returned after use will be handled by other actors in the value chain, within or outside of the industry, for value recovery (Berlin et al., 2022; Gou et al., 2008; Ning & Xin, 2021). Since the products are not returned to the manufacturer, there is no connection between the forward supply chain and RSC. This leads to a larger number of materials from different products that can be reprocessed compared to the case of CLSC. OLSC can be explained as "*a system that maximizes the value creation over the entire life cycle of a product including (re-)design, where the control and operation of the system, particularly reverse logistics and the remanufacturing process, is conducted by a diversity of business actors other than the OEM*" (Kalverkamp and Young (2019, p. 574)). An illustration of the fundamental logic of a OLSC can be seen in Figure 6.

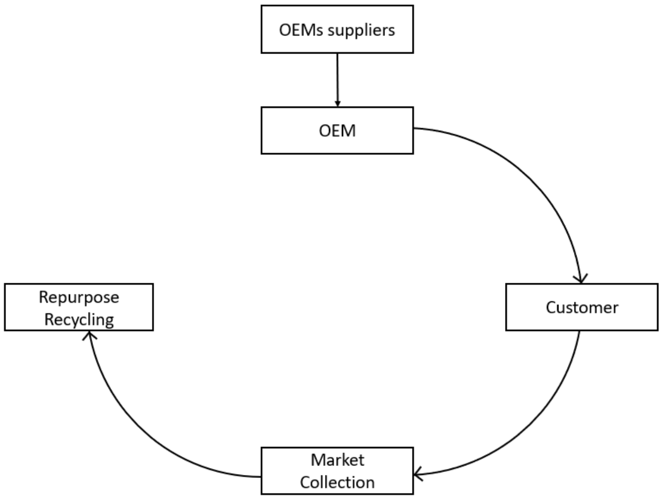

Figure 6. Illustration of an Open-Loop Supply Chain

The CLSC is more commonly used by companies since it is easier to establish (Kabir et al., 2021). The manufacturing company can build the CLSC by itself, without involving other parts in the process (Kabir et al., 2021). However, large manufacturers can benefit from using an OLSC instead of a CLSC, especially in an economic sense (Kabir et al., 2021). Furthermore, the OLSC creates an opportunity to create new entrepreneurs who can innovate and find new solutions to handle, reuse, repurpose and recycle more effectively, which is beneficial for the industry (Kabir et al., 2021; Kalverkamp & Young, 2019). By using an OLSC, manufacturers can likely benefit from open innovation and improvements of the products (Kalverkamp & Young, 2019). Due to the limitations of CLSC, there is a need to rearrange the system of the supply chains, where more industries prefer to implement open-loop (Kabir et al., 2021). Depending on the context, CSCs are, however, often arranged in a combination of OLSC and CLSC (Berlin et al., 2022). The comparison of the two different setups is summarised in Table 1.

Table 1. Comparison of the Differences Between OLSC and CLSC

	Closed-loop	**Open-loop**
Focus	Product recovery	Components and materials recovery
Ownership	Manufacturer responsibility	Market responsibility
Nr of actors	One too few	Many
Investments	Large	Small
Safety	Good for dangerous goods	
Innovation		Innovation in RSC

2.2.2 Circular Economy in Electric Vehicle Battery Context

Electrification of the automotive industry entails an increased need for circular flows to achieve sustainability. To achieve a transition that is sustainable in the long term, effective utilisation of EVBs needs to be established. Among industries, society and governments, there are a lot of concerns about the shortage of materials and their negative impact on society as well as the environment (Tankou et al., 2023). The batteries in today's electric vehicles contain critical materials such as cobalt and lithium (Chirumalla et al., 2024; Uhrdin et al., 2023). *Material that is critical means that they are crucial for the electric vehicle market and its development, in combination with issues regarding the reduced availability of the material due to price, environmental or ethical* *problems* (Ahuja et al., 2020). To avoid unsustainable extraction of these limited resources, a circular system of reuse, repurpose and recycling is required. Today, battery producers as well as truck manufacturers in the EU have a legal responsibility to take care of the batteries that they have produced when they become waste (Uhrdin et al., 2023). In the long term, market forces are expected to make it profitable to recycle components from electric trucks as they have a high economic value. For example, an increased demand for batteries as stationary storage of energy is expected, to relieve the electricity grid during fast charging or to ensure electricity supply at critical locations (Uhrdin et al., 2023).

The objective of CE requires that the utilisation of materials in batteries after they have reached their EOL in the electric trucks are maximised before considered waste (Chirumalla et al., 2024). To create a battery value chain that is sustainable there is a need to find solutions on how to decrease the batteries' impact on the environment and at the same time ensure that economic growth does not slow down (Chirumalla et al., 2024).

To mitigate the environmental impact of batteries, it is necessary to promote sustainable resource utilisation as well as waste minimisation, which can be achieved through the implementation of the 9R framework (Kirchherr et al., 2017). The framework is divided into three main areas, *smarter product use and manufacturing* (rethink, reduce, refuse), *to extend lifespan of product and its parts* (reuse, repair, remanufacture, refurbish, repurpose), and lastly *the useful application of materials* (recycle, recover) (Kirchherr et al., 2017). Most studies that have been performed on the topic of CLSC for EVBs focus on recycling batteries after use as the only option. However, the importance of other processes for taking care of the batteries has started to increase (Glöser-Chahoud et al., 2021).

The area *to extend the lifespan of a product and its parts* is the most valuable one to reach both the economic and environmental opportunities with battery circularity (Chirumalla et al., 2024). The 9R framework and the most relevant strategies for battery circularity can be seen in Figure 7. When the quality of the batteries is too poor to be reused or repurposed, the batteries should be recycled (Chirumalla et al., 2024). In the hierarchy of waste management, the reuse or repurpose of products and materials is considered to be better than recycling (Harper et al., 2019). Since LIBs have a significant economic value, the suggestion is to use LIBs in different ways to make better use of them and reduce their impact on the environment throughout their life (Harper et al., 2019). However, since the materials are critical, the recycling perspective is important as well.

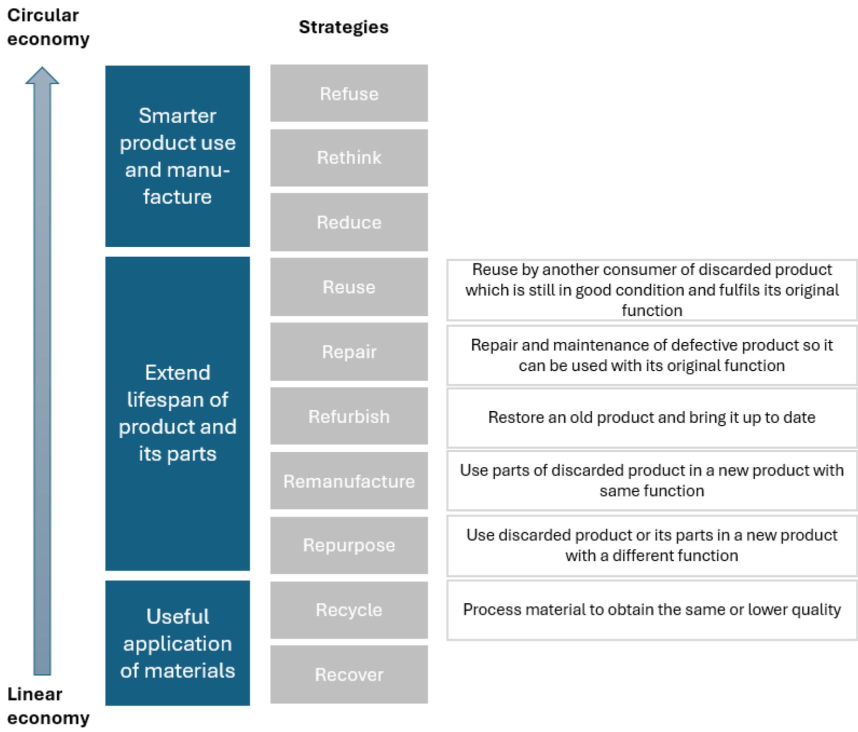

Figure 7. Illustration of the 9R framework. The strategies with descriptions are the most important in an EVB context. (Revised: Kirchherr et al., 2017).

In Figure 7 the 9R is presented as well as the description of the 6Rs that were considered to be most applicable to the thesis. In the following subsections, the most suitable strategies for the circular economy of batteries will be presented.

2.2.2.1 Reuse and Repurpose of Batteries

Reuse and repurposing are the most sustainable alternatives for electric vehicle batteries to handle resources effectively and minimise waste in the flow (Ahuja et al., 2020). *Reusing the batteries means that the batteries are used again in an EV*. This would be a preferable second use since it requires little resources and reconfiguration. *Repurpose*, on the other hand, *means that the batteries are used in another type of application*, for instance as energy storage (Ahuja et al., 2020). The state of health of the battery is an important factor in deciding if the battery should be reused or repurposed. When the batteries have reached their EOL in the trucks, they still hold on to around 80% of the battery capacity (Chirumalla et al., 2024; Glöser-Chahoud et al., 2021). However, this capacity is often too diminished to be effectively reused in another EV, but it can still have value for other applications through repurposing (Chirumalla et al., 2024).

The repurpose market for EVBs is today not established in a broader context; however, some repurpose is established by for instance using the batteries as stationary storage, when they have reached their EOL in the trucks (Dominish et al., 2021). Some other possible applications for repurposing EVBs are, for instance, EV charging and backup power (Guzek et al., 2024). The different manufacturers of vehicles as well as the stakeholders in the battery ecosystem are facing difficulties in getting their organisations ready for second-life operations (Chirumalla et al., 2024). The difficulties are particularly challenging when it comes to selecting and implementing circular business models that are suitable for EVBs. The increase in the variety of batteries in heavy-duty vehicles, and cars, as well as the differences in chemistry and sizes of batteries, creates complexity when it comes to designing the strategies for second-life use (Chirumalla et al., 2024).

Battery ownership, policy support and inter-industry partnerships are three factors that have been identified as crucial to making a second-life model function (Chirumalla et al., 2024). However, even if several stakeholders can see the benefits of different applications for a second-life, there are a lot of barriers to face. Some barriers are, for example, a lack of interest in business models, risks associated with investments and uncertainty of battery data transparency (Chirumalla et al., 2024). Furthermore, unclear regulations and technical challenges also affect the possibility of using the batteries in other applications after the EOL in trucks (Ahuja et al., 2020). Some factors that have been identified as enablers for second-life applications of batteries are; standardisation and design, testing, clarification and modification of existing regulations (Dominish et al., 2021).

The structure of the batteries today is designed by the different manufacturers based on the different requirements for their applications (Dominish et al., 2021). It is estimated that around 250 new electric vehicle models with different battery types from around 15 manufacturers will be on the market by 2025 (Engel et al., 2019). Since no standard on design exists, all these batteries will have their own design and form, which makes it harder to repurpose the batteries for other applications (Dominish et al., 2021). To enable second-life, it is also important that additional testing of the battery systems is in place to ensure the quality of the batteries. EVBs have a battery management system to control the function of the battery (Dominish et al., 2021). Today there is no standard in how the BMSs should be designed, there are a lot of different systems in place. This leads to the test of the health of the batteries cannot be done commonly and consistently, which in turn increases the costs of the process. This creates challenges particularly when manufacturers want to reuse the batteries since it requires a specific level of battery health (Dominish et al., 2021). Connected to this, a challenge when it comes to second use is the safety aspects as well as the uncertainty of how the battery has been used and handled during its first use (Ahuja et al., 2020). Another challenge to create a circular flow is the risk of reputational damage for the producer of the battery if the quality of the battery is lower than expected in the second use (Ahuja et al., 2020). Therefore, it is crucial to ensure that it is possible to assess the state of health of the battery before reuse.

Lastly, one barrier that needs to be overcome to be able to use the batteries in other applications is the challenge of collecting the batteries from the trucks (Dominish et al., 2021). In both the European Union and China, a framework is under construction to secure the handling of batteries after their EOL in vehicles (Tankou et al., 2023). The original equipment manufacturer (OEM) is responsible for handling and collecting their batteries after the EOL. To ensure the collection of batteries, a consolidated reserve-logistic system and collection of batteries between the OEMs can bring efficient transportation as well as cost savings for each manufacturer (Glöser-Chahoud et al., 2021).

2.2.2.2 Recycling of Batteries

The battery production requires raw materials that are of high quality and the materials needed are, as stated before, critical according to for instance the European Commission (Windisch-Kern et al., 2022). Therefore, the European Commission states that it is of significant importance to find strategies on how to pursue and recycle materials in an efficient way. When it comes to recycling, the process is not designed to recover all materials at a quality that is high enough to be able to produce new batteries (Dominish et al., 2021). Typically, the majority of processes focus on reclaiming the most valuable elements, primarily cobalt and nickel, to a standard suitable for producing cathodes for new batteries. Other metals like lithium and copper might either be recycled for use in different industries (downcycled) or lost during the process (Dominish et al., 2021). With the technology today, it is possible to recover metals such as cobalt, nickel, lithium, and copper, to over 90%, however, the process is limited in usage since they are extremely costly to perform (Dominish et al., 2021).

It is anticipated in the future that the battery content will have mandatory recycled content levels (European Parliament & Council, 2023), which puts a large pressure on the recycling process to make critical materials available from EOL batteries. The member states in the European Union have agreed that by the end of the year 2030, a minimum of 70% of the LIBs should be collected to enable an afterlife (Windisch-Kern et al., 2022). To reach that goal, there is a need to strengthen the technologies for recycling, but other initiatives have been taken to ensure collection. One initiative is the Battery Regulation which is constructed to ensure that batteries to a higher degree will be collected, reused, and lastly recycled (European Commission, 2023).

Recycling batteries after the EOL poses several challenges, some of the challenges are for instance: the lack of a standardised chemistry and design of batteries, as well as a process for recycling that still needs a lot of development (Ahuja et al., 2020). Connected to the lack of standards, one challenge is that even if the companies producing LIB batteries have similar designs, there are often larger differences when it comes to chemistries within the batteries. Since all batteries are recycled in the same facilities the different chemistries cause problems when it comes to recycling in an effective way (Dominish et al., 2021). In the future, the need for recycled materials from LIBs are crucial, since the demand for materials is higher than the supply of materials that are available from the recycled processes (Dominish et al., 2021). This means that new materials still need to be extracted. The recycled materials that are entering manufacturing today are in most cases from the few LIBs that have reached their EOL. Due to the technical process or differences in applications, it is unlikely that materials that have been used in other applications are used in the production of LIBs (Dominish et al., 2021).

Moreover, LIBs consist of materials that are classified as hazardous, since after their first use in trucks they still contain a lot of power, they pose several risks such as explosion, and toxic gaseous emissions (Ahuja et al., 2020). The batteries therefore pose a risk for both the environment as well as for humans, making it crucial to disassemble them in a way that reduces the risk of these outcomes happening (Glöser-Chahoud et al., 2021).

2.3 Product Variety

During recent years, there has been an increase in the number of variants of products in the market (ElMaraghy et al., 2013). *Product variety can be defined as differences in the used materials or using different production processes in the supply chain*. The variety in products can cause complexity when it comes to the ability to coordinate and configure the supply chain (ElMaraghy et al., 2013). Furthermore, product variety causes problems regarding the prediction of demand since the use of many different products makes it harder to estimate the demand for specific products. For a company that possesses a wide range of product variety, additional costs are created since it, for example, creates a need to hold a larger inventory (ElMaraghy et al., 2013).

Since the importance of reducing the dependency on natural resources, such as oil, as well as decreasing the environmental impact, the pace of development of EVs has accelerated (Sun et al., 2020). Since LIBs were introduced, there have been large developments in both battery chemistry and technologies connected to production and the development is constantly ongoing (Ciez & Whitacre, 2017). There is a constant development of LIBs to achieve higher energy density, improved safety, and longer driving range (X. Ma et al., 2021). This means that there are a large number of different batteries on the market. The following parts of the chapter will present the reason behind the variety in the battery context.

2.3.1. Variety in Batteries: Brand Differences and Design Impact

The vehicle manufacturers that are moving towards EVs have selected different paths in their battery development (Harper et al., 2019). The EVBs are today produced by different manufacturers that use different designs, materials as well as configurations, variations in the size of the battery and shape (Dominish et al., 2021). Together with the fact that the development of battery technology is rapid, there is an increase in the variety of different batteries available on the market (Chirumalla et al., 2024; Sun et al., 2020).

The development of EVBs and the variety it creates can also be seen between batteries produced by the same manufacturing company. The difference between the batteries within the same manufacturer arises as a consequence of the utilisation of, for example, different cell formats (Baazouzi et al., 2023). Additionally, the variety also appears because the cells are continuously developing, which causes variety within the cell formats (Baazouzi et al., 2023). Furthermore, battery chemistries as well as the design of the manufacturer's battery pack are constantly developing (Rajaeifar et al., 2022). The producers are not only using different cell formats in their batteries, but they also using different mixtures of chemistry, as well as developing their designs in different directions (Miao et al., 2019). Thus, the constant development, and changes in the design and content of the batteries, create a variety of EVBs.

To differentiate between different manufacturers' products and services, branding has been a prominent strategy (Townsend et al., 2013). In brand strategy, one of the most important factors is product design, which means that many companies invest large resources in development to improve their product/service design. In the automotive industry, innovation and design are important factors, which is partly due to the high cost of producing the products and the strategic importance these factors have (Townsend et al., 2013). In addition, the brand is a major deciding factor for companies in the automotive industry, where their brand has an important part in the valuation of the products and is of significant importance in creating a competitive advantage in the market. This also leads to that companies need to manage their brands carefully to not risk losing competitive advantage (Townsend et al., 2013). The transition to EVs is a part of the creation of a competitive advantage. The vehicle manufacturers that are currently investing in EVs have their own paths to create the optimal EV (Slowik et al., n.d.).

Today, battery capacity is a competitive advantage and an important argument when a consumer chooses between different products and brands (RISE, n.d.). To keep the competitive advantage, battery manufacturers are constantly developing the batteries to be the most attractive choice (RISE, n.d.). Thus, the constant development means that there is a large variety of batteries on the market, both in the form of configurations, as well as cell types and chemistry (Harper et al., 2019). Currently, there are a lot of different chemistry types in EVBs (Ahuja et al., 2020). The variety in chemistry can be partly explained by the fact that battery technology has not matured yet, but also since manufacturers want to experiment with their specific electrochemistry to obtain optimal battery performance to get a competitive advantage (Ahuja et al., 2020).

To ensure that the batteries are creating a competitive advantage for the company, many manufacturers are also cooperating with the producers of the LIB cells to ensure that they are developed to work together with the manufacturers' design of battery (Lowe et al., 2010). This could further explain the variety of design and chemistry.

2.4 Standardisation

Standardisation can be summarised as a voluntary establishment of common product characteristics, performance levels, product quality and safety guidelines (Viardot et al., 2021). The standardisation process is performed by different stakeholders who consider it to be valuable to have common characteristics of a product. In that way, a standard is a collection of the best practices, based on consensus, to develop the desired product or process and an agreement on what performance criteria should be met (Brown et al., 2010). The consensus is formed by various stakeholders like industry experts, academia, and government (Brown et al., 2010). One of the most well-known examples of standardised products is freight containers that have a standardised size of twenty-foot equivalent units (Menon Economics, 2018). The container standard was implemented to reduce the wide variety that existed between intermediate goods. Furthermore, as mentioned earlier, consumer batteries are an additional example of standardisation. When the consumer batteries were standardised, special dimensions and voltages of the batteries were determined (Turner & Sutter, 2022).

When discussing standards, it is important to distinguish them from regulations. When standards are created through the voluntary process, the industry can be seen as self-regulating and market-driven (Gupta & Lad, 1983; Büthe & Mattli, 2011). Regulations are on the other hand driven by governments to influence the market environment and behaviour of stakeholders (Blind et al., 2017).

2.4.1 Importance and Problems with Standardisation

Implementing standards can bring both opportunities and challenges. One potential risk of standardisation is that it might harm the growth of productivity (Menon Economics, 2018). A standard can lead to companies choosing the already established solutions and processes, which reduces innovation. Moreover, reduced innovation means that solutions capable of increasing productivity growth will never be found, resulting in lower growth than it needs to be (Menon Economics, 2018).

Although some might see standardisation as an obstacle to growth and innovation, others have pointed out that standardisation is a necessity for diffusing innovation and avoiding a fragmented market (Blind et al., 2017; Viardot, 2017; Viardot et al., 2021). Standards offer the market an innovation that has been accepted by most customers or end users (Viardot et al., 2021). Thus by lacking standards, the diffusion of technologies, which can benefit the environment or society is limited (Brem & Nylund, 2024). Standardisation creates a common ground for which knowledge can be exchanged resulting in increased economic efficiency in technological development (Brown et al., 2010).

A wide variety of products and/or services can lead to inefficient processes (Menon Economics, 2018). However, some benefits of standards, connected to the variety, are that they enable interchangeability and compatibility between different manufacturers of the same product (Castillo, 2015). Improving interoperability can lead to a reduction in transaction costs and have positive effects on the value chain, which in turn will lead to increased productivity (Menon Economics, 2018). Interchangeability encourages different innovative solutions from the supplier base as well as making the solutions work together, which fosters the development of new products, processes and services (Staudenmayer et al., 2005). Regulatory organisations can review the set standards to make sure that costs and operational performance are the best in the industry. Thus, enabling different actors a framework in which they can refer to when they are comparing products or benchmarking.

Furthermore, standards can also bring benefits when it comes to estimating the quality of both services and products (Menon Economics, 2018). Price and quality are the two parameters that are widely used when comparing two products, where the price is easy to compare while it is harder to compare the quality of products and services. The easiness of comparing a product or service quality would increase with a standard. Moreover, standards are in most cases positive for businesses when it comes to economic development as well as productivity (Menon Economics, 2018).

2.4.2 Standards for Electric Vehicle Batteries

Since EVs are expected to reduce negative environmental impact in the usage phase of transport, their adoption rate is important. As stated earlier, standardisation will be one important way to achieve faster market adoption (Pereirinha & Trovão, 2011). Presently, there exists no global standardised battery pack design for EVs, nor does it exist for modules or cells on an overarching level (Thompson et al., 2020). Even though standardisation has been recognised as important for EVBs (Tankou et al., 2023), it faces barriers and might make it unrealistic to create in the coming years (Meng et al., 2022). To further complicate things, the demand for mass customised battery design is increasing which results in trade-offs from a technical, societal, and commercial point of view (CIC energiGUNE, 2022).

Since the EVB market has a lack of standardisation, diffusion is limited, and adoption of heavy-duty electric vehicles is too. However, it is important to highlight that standardisation in the automotive industry is complex since there are a lot of interconnected technologies, processes and actors (Brem & Nylund, 2024). The market share that the EU holds in the EV market, gives the EU the possibility to establish standards which are accepted in the industry as a de facto (Melin et al., 2021). International standards for EV battery packs which are recognised by the industry are needed (Brown et al., 2010).

For a long time, inadequate batteries have been the major reason for the slow adoption of EV (Brown et al., 2010). However, battery technology is constantly evolving and both companies and governments are emphasising research and development. If a targeted technology is subject to standardisation while simultaneously undergoing rapid technological change, then forming a standard for those areas it is important to ensure to not limit technological development while promoting safety and environmental protection (Brown et al., 2010). In this context, standards can lead the way, rather than being a result of the reaction to technological development. The development of battery technology is not a hinder in itself to be able to create a standard but could mean that the standard needs to be updated more frequently. By ensuring that technological progression is considered, a future standard would help increase the acceptance of new technologies, resulting in economies of scale and ultimately leading to cost reduction (Brown et al., 2010). To further reach economies of scale, the standards must be consistent in different countries, meaning that they need to have an international scope.

However, one identified barrier to the standardisation of EVBs is the self-interest of OEMs to create and maintain a competitive advantage by keeping their battery system protected (Bhardwaj & Mostofi, 2022; Dominish et al., 2021). While the establishment of standards could help solve issues with batteries with regard to their reuse or recycling, the OEMs could face significant financial consequences (Dominish et al., 2021). There is a high probability that problems will arise for the manufacturers if a standard of the battery architecture is introduced, since the batteries are crucial for the strength and stability of the vehicle. Therefore, there is in the current state no regulations, standards or policies that are forcing the producers of EV to design and produce batteries that can work in all vehicles (Bhardwaj & Mostofi, 2022). It has been highlighted that improved standards are needed when it comes to methods to evaluate the suitability and requirements of a battery to be reused, i.e. state of health, performance levels and safety. Furthermore, improved standards are needed within the recycling process, for example when sorting different cells, modules, or packs, to ensure a more efficient recycling.

Areas like battery safety, durability and accessible information benefit from a standard since it will become easier for actors to exchange knowledge in these areas, resulting in improved reuse and recycling (Glöser-Chahoud et al., 2021). Without proper levels of information and performance in these areas, reuse and recycling cannot be optimised (Dominish et al., 2021; Glöser-Chahoud et al., 2021). Without a standard of both the battery pack and the cell level in combination, the problems connected with the transportation and handling of batteries will increase the overall costs of the battery and reduce the willingness to recycle (Thompson et al., 2020) With a lack of standardisation of EVBs, the most probable re-usage application will be direct collaboration between a specific OEM and energy companies (Dominish et al., 2021). The alternative would be for energy companies to source a variety of batteries.

A standardisation is also of importance to be able to decrease the cost of batteries (Perner & Vetter, 2015). To reduce the cost of an EVB, the degree of standardisation of its components has to be high. In Germany, a milestone was reached when the definition of standard battery cells for vehicles was established, which was beneficial with regard to industrialisation and cost (Perner & Vetter, 2015). However, the creation of a standard at the cell level could be complicated to achieve since the producers often use different cells like cylindrical, prismatic and pouch cells (Thompson et al., 2020).

From the literature, it can be understood that many different opportunities and challenges exist with the creation and implementation of a standard. The opportunities and challenges found in the literature are summarised in Table 2.

Table 2. Summary of the Opportunities and Challenges with Standardisation

Opportunities	***Challenges***
A standard would help increase the acceptance of new technologies, resulting in economies of scale.	There is a high probability that problems will arise for the manufactures if a standard of battery architecture would be introduced.
Improved standards are needed for methods to evaluate the suitability and requirements of a battery to be reused and for the recycling process.	OEMs could face significant financial consequences.
A standardisation is of importance to be able to decrease the cost of batteries.	The creation of a standard at the cell level could be more complicated to achieve since the producers use various battery cell formats.

2.4.3 Requirements for Implementing a Global Standard

In order to create and implement a standard there are several requirements. Looking at other industries and their requirements to create a successful standard, the marine industry has for instance found that funding, participatory and collaborative development is essential for a standard to succeed (Eger et al., 2022).

To understand the market and its requirements is crucial when creating and developing a standard (Gudmundsson et al., 2004). This is important to ensure that the standardisation actually is adding value and not reducing it. Additionally, it is important to have a plan for the supply network and the role that the strategic part in the chain has to ensure a successful standardisation (Gudmundsson et al., 2004).

For a long time, the European parliament have tried creating a standardised charger for phones, tablets, and cameras. Despite the effort to bring together the manufacturers in the industry, no standard was created (European Parliament, 2022). The charger standard has been seen as essential since it would make it easier for consumers to be able to use the same chargers for all applications as well as reduce the need for buying new chargers which will be good from an environmental point of view. Today, 11 000 ton of the electrical waste consists of brand-new chargers or chargers that no longer are needed (European Parliament, 2022). Since there was no effort from the industry to make a standardised charger, the European parliament established a law that ensures that all mobile phones, cameras, and tablets at the European Union market has an USB-C port for charging, regardless of the manufacturer. By this new law, there will be no need for consumers to buy their chargers from one specific manufacturer (European Parliament, 2022). In the case of chargers, there was a need for external pressure and regulations to ensure that the change was made.

To be able to implement a global standard there is a need for change in the organisations (Gudmundsson et al., 2004). All changes need to be considered and engage all internal as well as external stakeholders, which are affected by the changes that are going to be made (Ha, 2014). To implement a global standard, it is therefore crucial to involve the key stakeholders, to ensure that a common understanding of the needs is created (World Health Organisation, n.d.).

2.5 Theoretical Framework

To conclude this study´s literature, it consists of the four areas: battery structure, circular economy, variety, and standardisation. The EVB structure is a crucial part of the literature review to build an understanding of the different levels of a battery and their function. Furthermore, the area of variety builds a solid foundation as to why there is a need to find a common solution, where standardisation can be considered as an alternative.

The concept of CE is important to this work since it indicates the importance of creating a circular flow for the heavy-duty electric truck batteries and is an essential part of answering the second research question. From the literature review, it can also be said that standardisation could be a way to solve identified issues as well as creating a circular flow. CE in combination with standardisation is therefore the most important area of this literature review to answer the research questions of this work.

Based on the importance of the two areas, the theoretical framework, Figure 8, was created. As mentioned in the literature, CE can be divided into two different flows, open-loop-, and closed-loop supply chains. These two flows are built in different ways and have their opportunities and challenges. The CSCs can be created in different ways, and depending on the level of standardisation the different SC setups can be more or less suitable.

Furthermore, as mentioned in section 2.2.1, the creation of CSCs is not necessarily open or closed, but rather a combination of both. It can therefore be assumed that the CSC might need to be established in different ways depending on the level of standardisation of the battery.

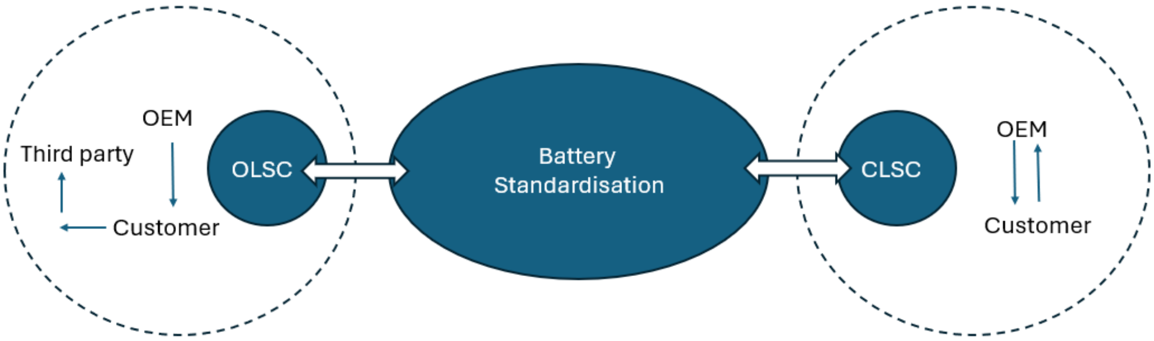

Figure 8. Illustration of the Theoretical Framework

3. Research Methodology

In this chapter, the research strategy will be described. Secondly, the process for data collection and the methods used for the collection will be presented. Furthermore, the chapter includes a description of the data analysis conducted on the collected data. Finally, in the last part of the chapter, the research quality is analysed.

3.1 Introduction to the Methodology

The thesis project has an investigating nature, and the subject area is at the forefront of research. Therefore, it was considered that an inductive approach was suitable for this project. Using the inductive approach creates a clear picture of the current situation and gives insights from the company's experience and knowledge. The study was performed at a global truck manufacturer. The company was, in this case, used to create in-depth knowledge of the current problems as well as how the research area would affect a manufacturing company of that size.

In the thesis project, qualitative methods were used. There are several reasons to adopt qualitative research methods. The methods can be used to understand the research participants' viewpoints and to explore subject areas which have not been thoroughly researched (Corbin & Strauss, 2015). For the mentioned reasons it was considered relevant to use qualitative research methods in the thesis project as the studied area is relatively new and prior research within heavy-duty electric truck batteries and standardisation was limited. Due to the sparse literature on the subject area, the study was performed to bring attention to the area rather than optimise or improve already existing theories on the subject area. However, even if the study is not focused on existing theories, already published literature and theories have been used to create an understanding of the industry and area, as well as understand the current and future problems.

3.2 Data Collection

The main sources that have been used to answer the research questions are literature studies and workshops. In the following sections, the different data collection methods will be presented.

3.2.1 Literature Review

As a first step, an initial literature search was conducted to gather knowledge within the area and to find relevant literature for problem formulation. A second literature review was then used to deepen the knowledge and provide more insights into the result of the data collection. A literature review consists of two different types of literature, previous research, and the theoretical perspective (Lindstedt, 2019). The first type of literature is useful for mapping out what has already been done in the field, while the second type of literature clarifies and explains the result of the work.

To find relevant literature in connection to the topic of the thesis project, different sources have been used. The online database Scopus, the search engine Google Scholar and Chalmers Library's collection of e-books and printed books have been used to collect the literature. The keywords used in the search are, but not limited to, *circular economy, closed- and open-loop, battery supply chain, electric vehicles, standardisation, reuse, recycling, reverse logistics, battery cell, battery module, battery pack, and lithium-ion batteries*.

The keywords were used on their own and in combination with each other. Scopus' "cited by (highest)" sorting function has been used to identify highly influential articles within the respective subject areas. To find and gather additional sources of information, the bibliography of some sources has been studied. During the literature review, date limitations on publications have been evaluated based on the characteristics of the subject area. Topics regarding battery technology and its applications have had a more recent and narrower date interval, whereas the definition of standardisation on the other hand had a less strict date interval. Moreover, unless stated otherwise all literature regarding battery technology and its application have been limited to the automotive industry to give as much relevant context to the thesis as possible.

From the many search results, the title of sources was evaluated to identify relevance to the thesis. The relevancy was evaluated based on the keywords, seeming connection to the topic, application of potential case studies and niche within the subject. If a title was deemed irrelevant, the article was discarded. If the title was deemed relevant or ambiguous, the abstract was studied. The evaluation of the abstract followed a similar pattern to the title evaluation. Finally, if the abstract was relevant to the thesis, the source was included in the review.

3.2.2 Workshop

Workshop is a method where a group of people come together to create new knowledge, solve problems, or innovate ideas for a specific area (Ørngreen & Levinsen, 2017). As a research methodology, workshops involve producing reliable as well as valid data in the relevant area for various forward-looking developments, such as organisational change. Thus, using workshops as a research methodology is a useful approach in studies that are emerging and unpredictable. Workshops were considered to be relevant for this master's thesis since the subject area is at the forefront of research and has a forward-looking nature.

There are two different types of methods that are used for workshops (Ørngreen & Levinsen, 2017). The first method is collaborative, which means that researchers and participants at the workshop work together to create new ideas, but the researcher has control over the workshop. In the second method, researchers work together with participants and contribute together to a mutual process where it is instead the participants who are in control. The first method, collaborative workshop, was used in this master thesis.

In this thesis project, two workshops (WS1, WS2) were conducted to understand what the selected key people from different parts of the company think about truck battery standardisation. The subject area was explored from both a societal perspective as well as what the participants have experienced in their work situations. As an introduction to the workshops, a presentation was held for the participants to give them insights into the research area. The workshop was divided into four different parts with questions, based on the aim of the study. The four parts were: *variety problems, standardisation opportunities, standardisation challenges* and *standardisation requirements*. The first part relates to the current problems with battery variety, which sets the stage for the next parts of the thesis project. The second and third part explores what opportunities and challenges the standardisation of a truck battery could bring. Lastly, the fourth part has a simultaneous perspective of the present situation and a future scenario, looking at what is needed to create a standard. The questions of each part were used to drive the discussions during the workshops to ensure that the answers were relevant to the thesis project. The questions were formulated based on the research questions and were divided into seven partial questions to make it easier for the participants to separate between the societal perspective and the company perspective. The questions that were discussed during the workshops, can be seen in Appendix A. Before conducting the workshops, a test workshop (WS0) was held with three selected participants, with relevant backgrounds, to ensure that the workshop's presentation, questions, and format were suitable for this research. Since the participants in the test workshop had relevant backgrounds, their thoughts and opinions could be part of data collection as well. The workshops lasted for approximately 45-60 minutes, where the participants had time to discuss the topics with each other and ask questions.

After the workshop, the participants received an online form, with the questions that were discussed during the workshop. The online form enabled the collection of the participant's reflections and opinions. Additionally, the online form allowed them to reflect on the discussions before providing their answers to the workshop questions. During the workshop, notes were taken which later on were transcribed as well.

3.2.3 Sampling

This study used a *non-probability sample* meaning that the sample of participants was based on some criteria and not on random selection (Bell et al., 2019). The goal for the researcher is to have a strategic selection of participants to ensure that the sample of choice is relevant to the research questions. The researcher wants to include a diverse group of people in the sample and select individuals who have different characteristics and knowledge that are important for the aim of the study (Bell et al., 2019).

Generic purposive sampling provides the possibility to gain knowledge from a broad number of positions in an organization (Bell et al., 2019). In the study, generic purposive sampling was used since it is necessary to get an understanding and knowledge from a variety of positions, with different knowledge and experiences, in the organisation. *Snowball sampling* was also a part of the sampling in this study. The snowball sampling is a method used to be able to reach a larger group of participants that can be of relevance to the research, by using an already identified group of participants (Bell et al., 2019). In this study snowball sampling was used to be able to reach out to people with the right set of knowledge and experience, by encouraging the already selected participants to invite other persons that they considered could be suitable and have relevant knowledge in the area.

The number of participants in a workshop should not be too large as the material processing is a time-consuming process. However, it is important that the number of participants is not too few since there must be enough material for interpretation and analysis (Dalen et al., 2015). Furthermore, having participants with relevant backgrounds and the ability to make a difference in the organisation is far more important than having a large number of participants with unsuitable experiences. Therefore, in this thesis project, it was considered to be more beneficial to have a few participants from the company to get a good understanding of the issues today and potential benefits and problems within the area of study. The persons were selected based on professional experience and knowledge of EVBs as well as environmental issues. Furthermore, the selection was made concerning that the persons should have a position in the company where they have the possibility to influence the development of the battery process.

The goal was to have 10-15 people present at the workshops, as the same interval is considered suitable for a master thesis which conducts interview studies (Blomqvist & Hallin, 2015). In the end, 14 participants were selected for the workshops. The participant's positions as well as in which workshop they participated are presented in Table 3.

Table 3. Sampling of Workshop Participants

Participant	Role	Workshop
1	Environmental Manager	WS0
2	Environmental Manager	WS0
3	Senior Project Manager	WS0
4	Environmental Director	WS1
5	Head of Quality and Environment	WS1
6	Senior Project manager	WS1
7	Sustainability Strategy Developer	WS1
8	Business Process Developer	WS1
9	Communication	WS1
10	Circular Business Developer	WS1
11	Circular Business Developer	WS1
12	Risk Manager	WS2
13	Head of Communication	WS2
14	Strategy and Special Projects	WS2

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3.3 Data Analysis

The following section describes the process undertaken to process the raw data into the final output. In addition, this section describes the validation process of the data analysis.

3.3.1 Analysis of the Workshop Data

The data from the workshop was collected both through the live discussions as well as through the participants' answers in the online form. As a first part of the data analysis, the raw data needs to be managed and cleaned (Bell et al., 2019). As a first step of managing the raw data collected in this thesis project, the responses from the online form as well as the notes and transcripts from the live discussions were reviewed. In the first part of the data cleaning information that was considered to be out of the scope of the thesis project was excluded. Moreover, the data cleaning in the online form consisted of clarifying any ambiguous answers, breaking down some answers into several pieces and moving responses between the four areas to create a better fit. After the first data cleaning the four main areas, *variety problems*, *standardisation opportunities*, *standardisation challenges* and *standardisation requirement*, had 39, 26, 31 and 21 data points respectively. After the cleaning has been performed, the researcher should find links between the different parts and create categories (Bell et al., 2019). The categorisation part is called *thematical analysis*.

Once the data had been cleaned, the data analysis could begin. To analyse the collected data, a *thematic analysis* was used. Thematical analysis is the most widely used analysis tool when it comes to analysing qualitative data (Bell et al., 2019). The thematic analysis is considered by some to be a type of coding, which means that the data is divided into smaller parts to make it simpler to handle. In this method, the researcher is looking for themes in the answers. Coding was made in two different levels in this master thesis. The first level of coding consists of summarizing what the participants said (Bell et al., 2019). In this master thesis, the first coding level was conducted by the authors and the company contact person individually. The coding was made with regards to being relevant to be able to answer the research questions. In the second level of coding, the codes are compared, consolidated and re-grouped (Bell et al., 2019). This level was made by sharing the codes, performed by the authors and the contact person, which were then harmonised into a final set of themes/categories. The harmonisation was done by reviewing the similar categories and identifying those that were different. The categories that differed were subjects of discussion, where consensus was reached.

3.3.2 Validation

After the data was cleaned and categorised, the final results were validated at three separate times by three selected key persons from the company that has extensive knowledge of the area. The validation was conducted by showing the final categories and their respective data points to the validation participant. During the validation, the cohesion of the categories, the chosen title for the categories and phrasing of data points were reviewed. The first validation was made with the company contact person for approximately 60 minutes. The second validation was conducted with a former workshop participant, which also lasted about 60 minutes. The third and final validation was made with a participant which had not been involved in the workshops and lasted for 35 minutes. The inputs that were received was used to combine some of the categories and change the names of some to make it easier to understand the different categories. Through these three validation rounds, the results of the data collection are validated, and the reliability of the thesis project is strengthened.

3.5 Research Quality

To ensure that the results are of high quality, the research must be ethical and trustworthy. Ethical aspects of the chosen methods must be considered to avoid any unethical practices. To evaluate the trustworthiness of the study, four different aspects: credibility, transferability, dependability, and confirmability need to be evaluated (Bell et al., 2019).

Credibility is crucial when it comes to assessing the reliability of results (Bell et al., 2019). The importance of this is particularly highlighted when it comes to understanding social reality and its complexity. In this thesis project credibility was ensured in many ways. Firstly, it was ensured by having diversity in knowledge and experience of the workshop participants. Secondly, by allowing the participants to write down their answers, the risk of misinterpreting a participant's opinion was reduced. Additionally, the transcriptions of the live discussions, allowed for using data without too much interpretation. Lastly, the results from the data collection were validated with the help of three persons at the company, to make sure that the final results matched the participants answers.

Transferability is another important factor to consider. Qualitative results tend to focus on the unique context and significance of what is being studied. The question of whether the results can be applied in other contexts, or even in the same context at a different time, is an empirical question that requires careful assessment (Bell et al., 2019). In this study, transferability was reached by studying the topics of circular economy, complexity of variety and standardisation. These topics are applicable for many other contexts, the subject area of heavy-duty electric truck batteries is just one possible application.

Dependability is the third aspect which needs consideration. It questions whether the results are likely to be true at other times and requires a description of the research process (Bell et al., 2019). In this thesis project, the method chapter acts as the main contributor to the dependability aspects, with descriptions of the workshop, data analysis process, and the participants.

Confirmability is the last aspect that needs to be considered. It is about examining the extent to which the researcher has allowed his or her values to influence the results (Bell et al., 2019). While complete objectivity may not be possible, it should be clear that the researcher has acted in good faith and has not allowed personal opinions to influence the meaning of the research or its results. As previously mentioned, by allowing the participants to write their answers and using quotes from the transcriptions it was ensured that the authors' opinions did not affect the result. This was further ensured by the validation of the data analysis.

There are several ethical aspects to consider when conducting qualitative research. When interviews and workshops are carried out, the researcher has to acknowledge consent requirements, confidentiality requirements and requirements to be informed (Dalen et al., 2015). First off, consent was only valid if the participant had previously received information about the research and the consent was documented. The consent must be voluntary, explicit, and specific to certain research. Furthermore, participants had the right to decide independently whether, for how long and under what conditions they would participate and if they wanted to discontinue their participation. Secondly, the participant's data was treated confidentially, and the participants were anonymous. Lastly, the participants were informed about the plan for the research, the purpose of the research and the methods that were used.

4. Empirical Findings

The following chapter presents the empirical findings from the workshops. The chapter is divided into four sections, one for each area that were discussed during the workshops. The first section *Variety Problems* identifies what problems that manufacturers or society faces due to battery variety. The second and third section, *Standardisation Opportunities and Challenges*, explores a future scenario of a battery standard and how it might impact the creation of CSCs. Lastly, the fourth section *Standardisation Requirements* describes what the creation of standardization will require to become a reality. The resulting categories for each section from the cluster analysis can be viewed in Table 4. The data in this chapter stems from the participants' responses that were received from the digital form. Statements that are taken directly from the workshop discussions are referenced with WS1 or WS2 to indicate in which workshop the statements were made. Data points which stem from the online form will not be referenced with WS1 or WS2.

Table 4. Illustrates the Final Categories for the Four Main Areas

Variety Problems	**Standardisation Opportunities**	**Standardisation Challenges**	**Standardisation Requirements**
Production Complexity	Production Efficiency	Production Changes	Definition & Specifications
Value Chain Complexity	Business Potentials	Business Risks	Consensus
Aftermarket & Workshops	Unified Technology	Hinders Innovation	Circularity
Reuse & Repurpose Complexity	Reduced Lock-in Effect	Value Chain Adaptation	Technology Maturity
Recycling Complexity	Value Chain Improvement	Environmental Risks	External Party
Diverse Technology	Improved Reuse & Repurpose		
	Environmental Gains		

4.1 Variety Problems

In the discussions during the workshop, it was presented that one key reason behind the amount of variety is the customisation of the product to fit the customer's needs (WS1). Another key reason that was brought up is the large investments in developing and producing batteries, which means that all the manufacturers want to be able to achieve profit on the process (WS2). With today's battery variety follows several problems for Original Equipment Manufacturers (OEMs) and society that the participants were able to point out. The identified categories of responses were: *Production Complexity*, *Value Chain Complexity*, *Aftermarket & Workshops*, *Reuse & Repurpose Complexity*, *Recycling Complexity*, and *Diverse Technology*.

The weight of the categories can be seen in Figure 9 below, where the circle size indicates how frequently the area was mentioned by the participants. The larger the size, the more frequently it was mentioned in the workshops. For example, *Recycling Complexity* had the lowest answer frequency while answers connected to *Aftermarket & Workshops* had the highest answer frequency.

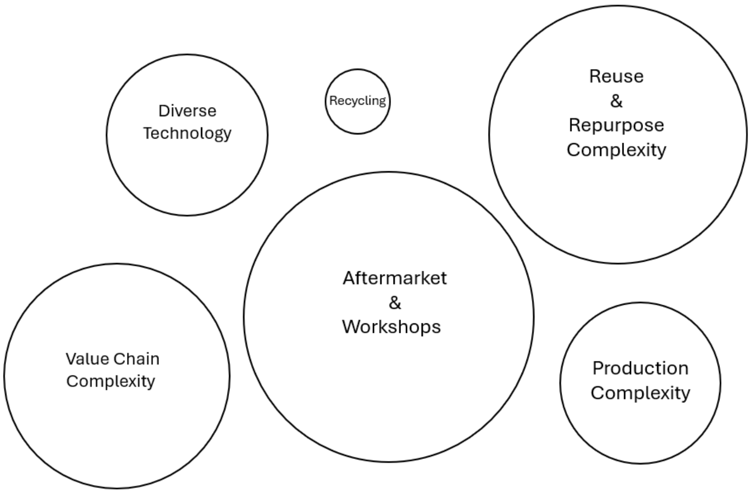

Figure 9. Weight Illustration from the Cluster Analysis for Variety Problems

4.1.1 Production Complexity

To encapsulate all the problems which arise in the production environment, the category was given the name Production Complexity. Although it is crucial to satisfy the customer's needs, the participants point out that variety reduces the efficiency of production operations. One participant also mentioned that the variety causes problems with line balancing. The production needs to consider that different generations of truck batteries require different amounts of time to assemble and install onto the truck, which is a problem for the fast-paced production environment. One participant also mentioned that the more variety they have between the batteries in their production, the more updates need to be handled (WS1).

The battery variety does not only affect the production outcome, but it also affects safety in production. Different batteries contain different energy content, meaning that some batteries are more powerful than others and thus more dangerous. The effect that the batteries have on the production can be highlighted with the following quote: "*Facilities in plants may have to be adjusted based on risk assessment from handling of different batteries (energy content)*".

4.1.2 Value Chain Complexity

The overall complexity in the value chain will increase, with an increase in product variety. Whenever there is a product change, the value chain will be affected. This change could mean that suppliers need to adjust their processes, the manufacturers might have to procure new materials and the dealers must update their knowledge in connection with the product. Throughout the batteries' lifetime, the manufacturer must collect data on usage, which means that more information must be logged and maintained than ever before. The information serves not only the manufacturer but is required to comply with sustainability regulations. One participant mentioned that it is hard to harmonise the different regulations that are set on the batteries, such as the Battery regulation which is set by the EU.

4.1.3 Aftermarket & Workshops

The category Aftermarket & Workshops encapsulates the variety problems which arise in the aftermarket and workshops. Inventory management and its associated logistics was the most prominent responses of all problems related to battery variety. Several participants highlighted that the complexity of handling spare part storage increases with more variety of spare parts. Keeping track of spare parts in different locations, for different models creates difficulties as well as increased costs.

Furthermore, the participants brought up the problems which arise in the aftermarket. Workshops and dealers must receive the right training and competence for the different truck models and battery combinations to properly serve their customers. Furthermore, they will need the right tools and equipment to be able to work on the truck. Service, maintenance, upgrading and repairs are all areas which become increasingly more complex and difficult to perform with an increased amount of battery types.

4.1.4 Reuse and Repurpose Complexity

It became clear through the participants' responses that the batteries' next steps in a circular value chain are difficult to handle. The category Reuse and Repurpose Complexity contains all the responses connected to problems which arise in reuse and repurpose context of electric truck batteries. Among the responses, many pointed out that the battery variety causes problems for repurpose applications. For example, actors who perform refurbishment or remanufacturing need to have agile processes to accommodate the different battery types. Although energy storage systems have been viewed as a potential application, there are still uncertainties among manufacturers about other possible applications for the value creation of electric truck batteries. The following quote highlights the concern of reutilising the batteries, "*Most likely, there will be increased complexity in the ability to use these various types in second-life applications*".

Since there are a large number of battery variants in the market stemming from different brands as well as different generations of these brand batteries, there is a lack of interoperability. Thus, there is a challenge for customers when it comes to replacing batteries in the trucks, both between brands and within brands. The participants mentioned that there will be problems within the brand because different generations of batteries come in different sizes, which creates complexity in the replacement.

"*Limited or no backward compatibility (i.e. difficult to replace batteries in old vehicles with new batteries)*". As the quote highlights, a new battery is harder to adapt to vehicles with previous generations of batteries. Thus, it is harder to change the batteries to get the newest battery technology. To get the new batteries, a larger change of the truck is necessary, and will therefore be a complex process.

4.1.5 Recycling Complexity

Recycling is its own category due to the problems that recycling faces problems of the amount of variety between generations and across manufacturing brands. From a societal point of view, it is important to be able to reutilise critical material. One of the respondents pointed out that the variety of batteries reduces the ability for optimizing the recycling process. The participant stated that this is due to that the variety increases the complexity since the process than have to manage and take care of all different batteries. Other answers that were received in the online form pointed out that recycling is a problem caused by the variety.

4.1.6 Diverse Technology

Although not entirely an answer to what problems the battery variety causes, there were a lot of discussions on why the market is fragmented according to different technologies. As battery technology is still quite novel to the market, the development is moving rapidly. Since the development is fragmented across different manufacturers there is an anxiousness that patents can at worst restrict some development areas. The manufacturers face a lot of uncertainty regarding what the battery content will look like in the future. Perhaps the battery chemistry or design will evolve into something vastly different from today's format. The aspects of fragmented battery technology and rapid development are categorised together as Diverse Technology. Even if the category might not answer what problems are arising, the understanding of the background to the variety and its problems is considered to be important.

4.1.7 Summary

The empirical findings presented in the sections 4.1.1-4.1.6 answers the first research question; *What type of circular value chain problems arise today due to heavy-duty electric truck battery variety?* The previous sections describes that the variety are causing problem within the categories: *Production Complexity, Value Chain Complexity, Aftermarket & Workshops, Reuse & Repurpose Complexity, Recycling Complexity* and *Diverse Technology*. Most problems that arise today due to the battery variety was found within the category Aftermarket & Workshops, where problems with, for instance, inventory complexity, inefficient logistics as well as maintenance complexity were identified. The problems that were identified in by the participants are summarised in Figure 10 below.

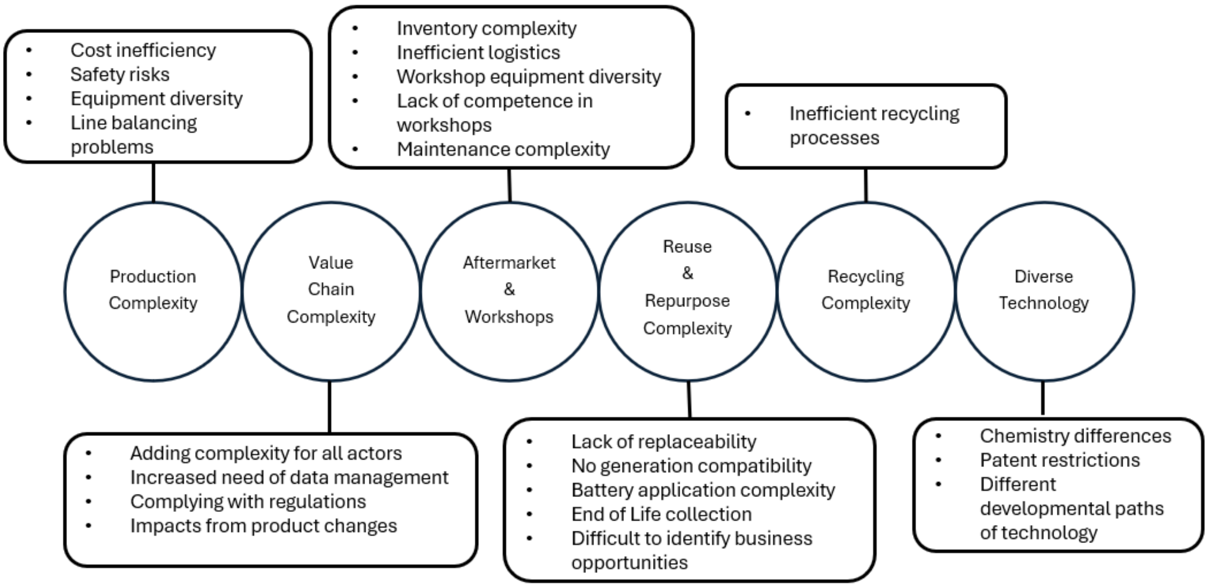

Figure 10. Illustration of the Variety Problem Categories and their Individual Datapoints

4.2 Standardisation Opportunities

During the second part of the workshop, the participants were asked to discuss the opportunities with a standardisation of a truck battery could bring to OEMs as well as to society. Several of the participants mentioned that battery standardisation can bring different opportunities to different actors depending on what level of the battery that will be standardised (WS1, WS2). One participant mentioned that benefits could be achieved for the battery providers as well as for recycling organisations depending on the aim of the standardisation and which part of the battery that will be standardised (WS1). The participants were able to point out several aspects concerning opportunities with a standard of heavy-duty electric truck batteries. The responses connected to standardisation opportunities could be categorized into; *Production Efficiency, Business Potentials, Unified Technology, Reduced Lock-in Effect, Value Chain Improvement, Simplified Reuse and Repurpose, and Environmental Gains*. Figure 11 illustrates the weighting of the respective categories according to response frequency, in the same way as for the previous categories.

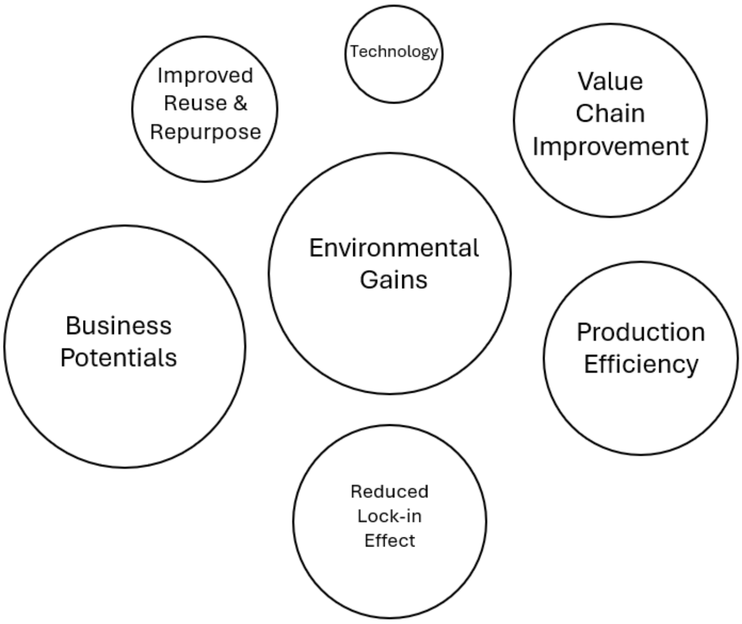

Figure 11. Weight Illustration from the Cluster Analysis for Standardisation Opportunities

4.2.1 Production Efficiency

With the standardisation of truck batteries, several opportunities were mentioned by the participants which could be categorised together as Production Efficiency. One of the participants mentioned that the standardisation would enable "*higher volumes for production".* Furthermore, economy of scale in production together with business decisions were stated as opportunities with battery standardisation, as highlighted by the following quote *"The enabling of better business decisions from "make-buy" when competition and OEM economy of scale is working better".*

Another participant stated that standardisation will bring the possibility to create one setup in the production. One set-up makes it possible to use the same equipment and machinery for all new products introduced within the OEM. The simplification of one set-up was mentioned during both workshops where the participants stated that standardisation would be convenient from the OEMs perspective. The participants stated that a standardisation of battery dimensions would be the most convenient from the OEM's point of view regardless of if it concerns the cell, module, or pack level (WS1, WS2).

Furthermore, it was mentioned that a battery standardisation brings opportunities when it comes to optimising the production process as well as the safety standards that exist in production today. The design of the truck was another point that was brought up which would help reduce complexity for the OEMs. A participant stated that a standard of the truck battery would bring "*A simplified baseline for modularisation in the truck design.".*

4.2.2 Business Potentials

The largest number of answers and discussions about opportunities were connected to the business models. The opportunities mentioned were, for example, connected to cost impacts and increased market access. The most frequent answer was related to the cost perspective. One of the participants stated that *"cost is always important for manufacturer as well as customers and needs to be taken into consideration".* Other inputs on the cost aspects of standardisation were "*lower cost*" and that "*it probably has a direct cost impact*". Additionally, one participant mentioned a business opportunity in increased market access. A standardised battery would mean that the battery can operate in the same way in many different markets. To encapsulate the cost impacts and increased market access the category was given the name Business Potentials.

4.2.3 Unified Technology

One area of opportunities that was mentioned by the participants was the technology and development of batteries. One participant mentioned that an implementation of a standard can, for instance, be beneficial since it can provide a specific measurement method which enables the manufacturers to compare their products. Another participant stated that a standardised battery for trucks could bring benefits regarding the development of the infrastructure. The participant also noted that the standard would simplify the infrastructure development. The responses and discussions all point towards the fact that a unified technology, meaning a potential standardisation, will simplify the applications and infrastructures connected to the battery technology. Thus, the category was assigned the name Unified Technology.

4.2.4 Reduced Lock-in Effect

The perspective of the customers was a category that was mentioned by several of the participants. The variety of batteries on the market today creates different types of problems for the users and customers of the trucks. One of the participants mentioned that a standardisation of the truck battery probably will make it simpler to change and replace one battery with another if needed. This ability to change and replace the battery will result in a reduced lock-in effect for the customers, meaning that entry and exit barriers are lower. Another participant mentioned the possibility for customers to easily compare products between the different brands before deciding on which brand to buy from. Additionally, there is potential for the heavy-duty electric truck batteries to achieve better quality and performance at a lower cost, which would be beneficial for the customers.

Another aspect that was discussed regarding the standardisation's impact on the business was the importance of brand-specific solutions. One of the participants stated the following:*" There might be a brand image or other reason to keep brand-specific solutions, it might not always be a good decision though if we learn from the iPad/iPhone cables".* Furthermore, the participant mentioned that it could be an opportunity to have a standard and thereby reduce the brand specific solutions. In the end to encapsulate the aspects related to customers' increased ability to choose the category of Reduced Lock-in Effect was formed.

4.2.5 Value Chain Improvement

Several of the participants mentioned opportunities connected to different parts of the value chain, these opportunities were categorised as Value Chain Improvement. One example is a participant who stated that a standard would make it easier for all different actors in the value chain. The value creation would not only become easier, but it is also possible that standardisation would create higher value for several actors in the value chain. In line with this, another participant, mentioned that a standardised battery would simplify the maintenance, which also would bring value to several actors in the value chain. Lastly, there is an opportunity to reduce the need for regulations. One of the participants highlighted this in the online form by the following quote, "*Regulations and safety risk reduction (rigorous testing)"*.

4.2.6 Improved Reuse and Repurpose

One of the identified categories of opportunities with standardisation of truck batteries is related to improving the second use of batteries after they have been used in the trucks. This category of opportunities was thus given the name Improved Reuse and Repurpose. Among the respondents' answers, one mentioned that the standardisation would make the use of batteries in other industrial setups much easier. Moreover, another respondent emphasised the efficiency gains that standardisation would bring, and pointed out that it will "*Simplified repair/remanufacturing processes*".

All the participants that mentioned the second-life category as an opportunity agreed that a standardisation of batteries in trucks would be a pivotal step towards optimising the second use. One of the participants mentioned this by pointing at that it could make it easier for the society, *"For a society it could then be easier to plan logistic for re-charging spots in towns, support farms and reuse the batteries in other vehicles."*.

4.2.7 Environmental Gains

Several of the participants mentioned environmental aspects as opportunities with a standard for truck batteries, these opportunities were grouped together as Environmental Gains. One of the participants commented that it is crucial to stay within the bounds of the earth but at the same time allow transportation since it is necessary. The participant also commented that standardisation might be a way to ensure this (WS2).

Among the answers, most participants stated that a standard will bring benefits related to the recycling process of the battery. Some of the participants stated that it would make it easier to optimise the recycling process, while another participant mentioned *"Improved opportunities to set up and support large-scale recycling facilities"*.

Connected to the scaling and optimisation of recycling, one of the participants also mentioned that the standardisation enables partnerships between the brands to setup recycling facilities. Another perspective that was mentioned by the participants was the opportunity to decrease the environmental effects of the batteries. One of the participants mentioned that an introduction of standardisation would, for example, reduce the negative environmental effects that the batteries have trough banning of certain components.

4.2.8 Summary

In the empirical findings sections 4.2.1-4.2.7, it is possible to see that there are many standardisation opportunities in an electric truck battery context. The standardisation opportunities can be clustered into the following categories: *Production Efficiency, Business Potentials, Technology Convergence, Customers' Empowerment, Value chain, Ease of Second life, and Environmental gains*. In each cluster category, individual opportunities have been grouped. The individual opportunities and their category can be seen in Figure 12.

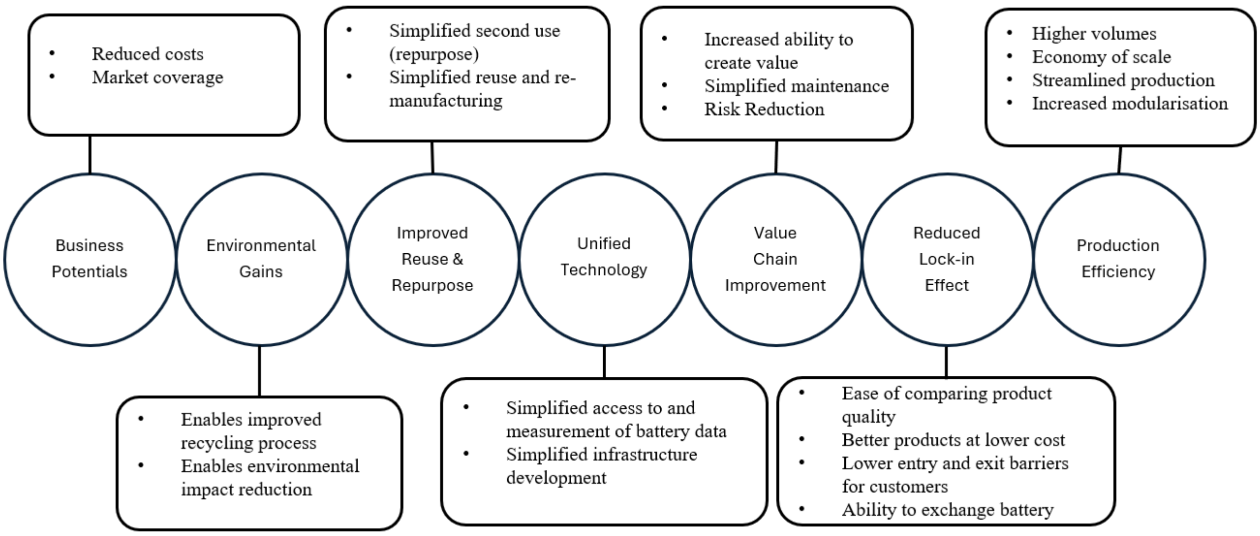

Figure 12. Illustration of the Standardisation Opportunities Categories and their Individual Datapoints

4.3 Standardisation Challenges

In the workshops, the participants also pointed out the challenges that a standardisation of heavy-duty electric truck batteries would entail. Responses which indicated challenges could fall into the following categories: *Production Changes, Business Risks, Hinders Innovation, Value Chain Adaptation, and Environmental Risks*. It is possible to view the relative weight of each category in Figure 13. Like before, the circle size indicates relative frequency of category responses or discussions compared to each other.

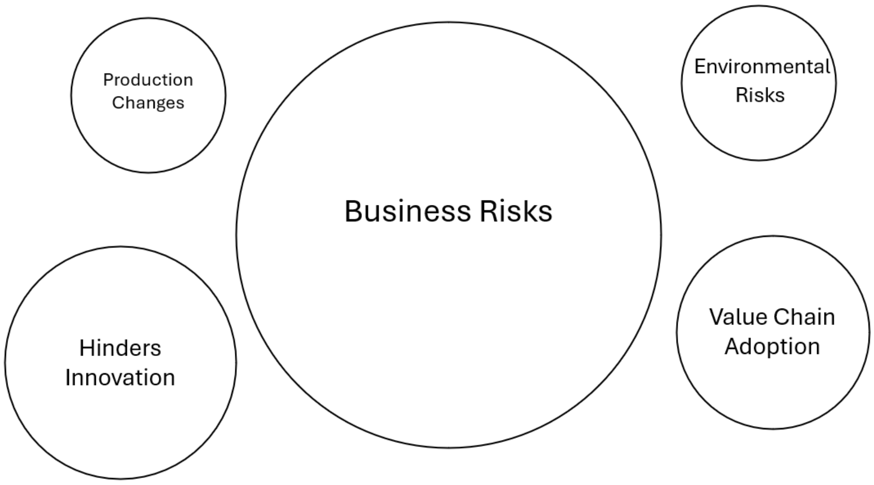

Figure 13. Weight Illustration from the Cluster Analysis for Standardisation Challenges

4.3.1 Production Changes

Challenges related to the production environment were grouped together as Production Changes. The creation of an electric truck battery standard would influence the manufacturers' production line. The Case Company is already manufacturing battery packs. Thus, a change in battery packs will result in changes to preassembly in production as well as equipment. One of the participants mentioned that implementing a standard would influence, for example, the production line, leading to changes on the production line, which could have an impact on the line balance today (WS1). Furthermore, the participant noted that implementing this change will probably add additional cost. The added cost might need to be placed on the customer, which in turn might lead to that fewer customers are willing to buy the electric trucks (WS1). Furthermore, the knowledge and competence of assembly workers would have to be updated to accompany the change in the battery pack. One of the participants mentioned that the standardisation might can lead to an expensive transition and anticipated investments, depending on what level of the battery that standardised, and which changes that are required.

Another challenge that was mentioned by one of the participants during the second workshop was that a global standard would make it harder to optimise production as well as cost and quality (WS2). However, it is important to remember that trucks within the studied OEM are produced according to customer requirements, thus battery standardisation has to keep in mind that the requirements differ depending on application (WS1). Taking the battery application into account was pointed out by other participants concerning standardisation adjustments in truck and battery production (WS1).

4.3.2 Business Risks

Responses which could be connected to business aspects were the most prominent in relation to standardisation challenges, resulting in a Business Risk category. Several of the challenges that were mentioned regarded the loss of competitive advantage or threats to the business model. One of the participants stated that battery standardisation can be a competitive disadvantage for the company and that it "*can diminish opportunities for* *differentiation and branding"*. Another mentioned that battery standardisation would be a "*Threat to current business models and profitability*". One of the other participants mentioned the aspect of competitiveness and stated that the battery standardisation would reduce the uniqueness of the company's batteries as highlighted by the quote: *"It would take away the "uniqueness" in that aspect."*. One of the participants states that lack of uniqueness would be a limitation since the Case Company´s business offering is built on having a high degree of customer adaptation. Their high degree of customisation is, for many buyers, the reason to choose the Case Company over other OEMs. Thus, the business offering does not allow a high degree of standardisation. In that sense, standardisation might hurt the company´s reputation (WS1).

Furthermore, connected to the loss of uniqueness, one of the participants stated that it would also mean that everyone knows the setup. This could also be a risk of losing competitive advantage. Moreover, one challenge could also be to be able to give solutions for all the different customer applications and adapt the battery after the customers' requests. From a manufacturer's point of view, a battery standardisation could lead to a limitation of choice or customisation for the customers.

Implementing battery standardisation has generally been seen as a business risk and a threat to the Case Company´s competitive advantage in the workshops. Although the business risk was a prominent concern in all workshops, this narrative was questioned by one of the participants. In the case of consumer batteries, the participant pointed out, some of the actors have been able to achieve a competitive advantage even if consumer batteries are standardised. Thus, the participant pointed out that the manufacturers can achieve a competitive advantage even if a standard is implemented (WS2). A truck manufacturer could follow a standard but adapt some parts of the battery to create a competitive advantage like in the case of actors in the market of consumer batteries. As many participants were concerned about business risks, this aspect was included in the challenge category, but a battery standardisation does not necessarily have to result in the loss of a competitive advantage.

Several of the participants mentioned that the battery is considered to be a strategic component for the business. One of the participants pointed out that it is primarily the battery cell which is crucial to be able to create a competitive battery pack (WS2). Others highlight the company's self-interest in making unique batteries and that a standard would hinder this. The self-interest in combination with the battery as a strategic part, makes it hard to implement a new type of battery in the production and it will at the same time hurt the business (WS1).

Another aspect that was mentioned as a standardisation challenge was the effect it would have on the aftermarket and the company´s position on it. One of the participants mentioned that it can be a problem to persuade the OEMs to be a part of the creation and implementation of the standard since they probably not are willing to give their specific company´s knowledge away to create an industry battery (WS2). Furthermore, the participant comments that a standard will open up for other actors in the chain to sell the spare parts in the aftermarket, which will reduce the OEM´s market share in the aftermarket, which today is an important part of the business.

Lastly, supply risks were mentioned during the workshops. The participants mentioned this as a risk since they meant that if the standard were to be set on the materials or chemistries it would mean that the pressure on the selected materials would increase. If the demand for the materials increases this could lead to increased demand and reduce ability for the OEMs to buy the products from their suppliers. This could in turn increase the costs for these materials or create disruptions in availability, as in the case of semiconductors.

4.3.3 Hinders Innovation

Many challenges regarding innovation and technological development were pointed out and to capture them the category Hinders Innovation was created. An opinion that weighed heavily amongst the participants was how standardisation related to technological development. "*Hinder technical innovations*" was a frequently used comment during the workshops and in the online form. The standardisation could restrict innovation by putting the electric truck battery within design, shape, or content boundaries. The participants mentioned that the standard could mean that the technical innovation will be hindered, and as a consequence, the best solution might not be found.

In connection to innovation constraints, one participant expressed that the biggest challenge would be that the design is dependent on what level of the battery that would be standardised. Furthermore, there could be a risk in choosing what batteries to procure if the battery content is not well defined in a standard. If battery content is ambiguous, then there is a risk of variations in the energy output. Another point made by the participants is the need to re-design previous versions of trucks to comply with new battery standards. Moreover, one respondent pointed out infrastructure as an important aspect to consider. The participant stated that there needs to be general commitment to infrastructure investments as many actors are dependent on them.

Today LIBs are dominating the electrification, but in the future, there might be another battery technology dominating. New technological shifts can occur; thus, a standard would quickly become outdated. Therefore, several participants stated that it is important to reach a mature technology before implementing a standard. One participant suggested that the global journey towards a global standard might have to look like the European emission standard journey of Euro 1 up until Euro 7 today. Thus, setting a global standard for a truck battery will happen in steps over a long time, rather than a full concept overnight.

4.3.4 Value Chain Adaption

One challenge, identified by the participants, with adopting a standardised truck battery, is the setup of existing supply chains. The current supply chains would have to adapt to the new scenario of a standardised battery, which would also result in that processes and actors in the chain would have to be harmonised. However, changes in the supply chain could be difficult as the supply chain could show inflexibility. Furthermore, a concern which is expressed in the responses is that standardisation risks becoming a one-size-fits-all situation. One of the participants mentioned that "*Society in one region may be more impacted than another, based on climate, wealth, existing infrastructure, existing local laws*". Taking into consideration that circumstances differ between different regions will be important in the adoption of a battery standard.

Another challenge that was mentioned during one of the workshops was the cost for the customers. A battery standard, as mentioned in previous sections, might have an impact of the overall cost of the trucks, which in turn will increase the market price for the customers. This in turn could reduce the willingness for buying an electric truck. One participant stated that even if the batteries were standardised, they might not be able to bring value through their reuse or repurpose in other parts of the supply chain (WS2). The participant mentions that even if it was possible to use the batteries in other context, for instance energy storage, the truck batteries would not be the most effective ones for these applications (WS2). To capture the identified challenges regarding the existing supply chains, the category Value Chain Adaptation was formed.

4.3.5 Environmental Risks

Environmental aspects connected to the creation and adoption of standardised truck batteries were brought up in the workshop discussions and in the online form. These environmental challenges were grouped together in the category Environmental Risks. Although a standardised electric truck battery would enable value for second-life applications and materials recovery through recycling, the growing demand for batteries puts a large demand for critical materials. A battery standard would not eliminate the resource intensity, even though it would help utilise the already extracted materials for a longer period, by enabling a simplified reuse. Depending on how the standard is designed and formulated, it might even increase the pressure on selected resources. Additionally, the participants expressed concern that there is a quality risk and exploitation risk in procuring batteries from a supplier if the manufacturer themselves cannot ensure that the supplier puts priority on environmental and social issues. Furthermore, cost is an important aspect of value chains, and generally, it is cheaper to procure from suppliers who are less concerned about environmental issues. Another respondent describes the potential risk that society, the customers, has to take the responsibility of collecting the batteries and setting up structures to enable batteries to be used in a second-life application or the dismantling of the battery packs.

4.3.6 Summary

From the previous sections 4.3.1-4.3.5, it is possible to see that a battery standardisation would not only bring opportunities but also risks and challenges. The challenges could be categorised into the following: *Business Risks, Production Changes, Environmental Risks, Hinders Innovation* and *Value chain Adaptation.* These need to be considered when discussing a battery standardisation. The standardisation challenges categories and their individual data points can be seen in Figure 14.

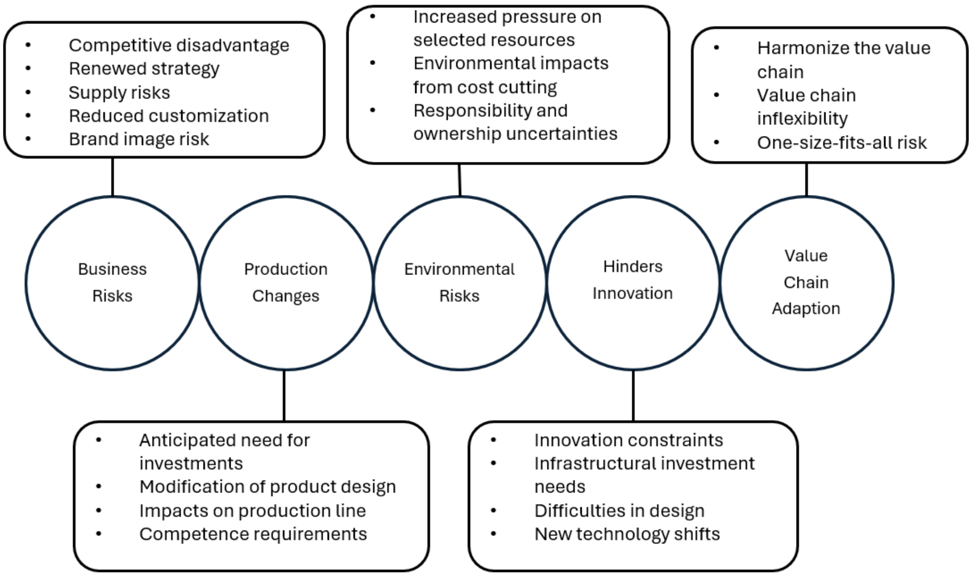

Figure 14. Illustration of the Standardisation Challenges Categories and their Individual Datapoints

4.4 Standardisation Requirements

After discussions on both the current problems with battery variety and the possible outcomes of a future battery standardisation scenario, the focus shifted to requirements that are needed to reach a standardisation of electric truck batteries. The discussions included a lot of different aspects and how the process would have to proceed. During the workshop discussions, it became clear that which level of the battery that is standardised is the most important aspect to clarify. The responses could be categorized into: *Definition & Specifications*, *Consensus*, *Circularity*, *Technology Maturity*, and *External Party*. The different weights of the Standardisation Requirement categories can be seen in Figure 15.

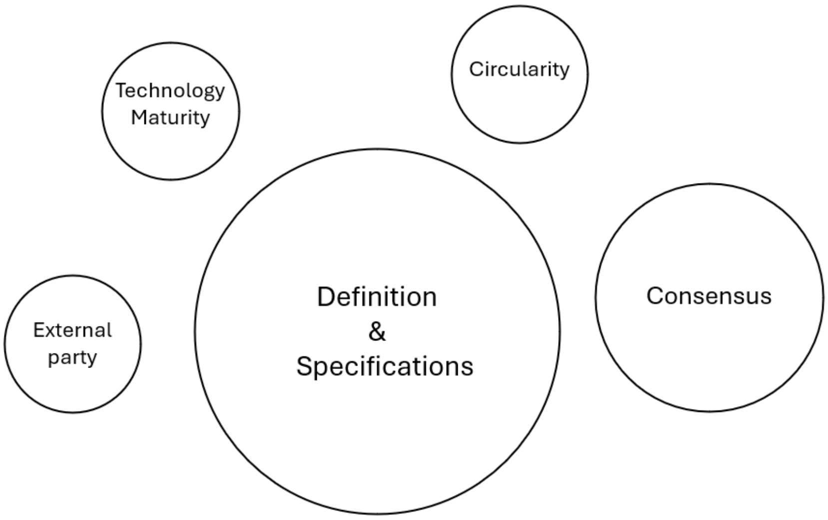

Figure 15. Weight Illustration from the Cluster Analysis for Standardisation Requirements

4.4.1 Definition & Specifications

Many of the responses regarded what needs to be standardized, which were categorised as Definition & Specifications. For instance, many participants questioned if the standardisation would regard the interface between the application and the battery, the application, or if it is the battery itself. Furthermore, the participants discussed how the standardisation should be designed and formulated. Questions regarding a standard on the battery itself and on what level or area of the battery that then would be standardised were discussed. The participants argued that a standardisation would have different impacts depending on how the standard is defined. One participant argued that a standardisation of cells or packs might be possible, but the module is design-dependent and thus better to keep it different between the batteries. One of the participants commented that the design of both the modules as well as the packs depends on where on the electric truck the battery is supposed to be located (WS2). Another aspect that was brough up was that there must be clear definitions and specifications of the standard to make sure that different stakeholders have a common understanding.

One of the discussions during the second workshop was about which perspective of standardisation that should be considered. The participants in that workshop mentioned that it is an important aspect to understand, who drives the process of standardisation and what the objective of the implementation is (WS2).

"One must constantly return to, what is the purpose of the standard? There is a greater purpose for the environment than for the OEMs. There is a climate threat, and the clock is ticking, we must move towards fossil-free" (WS2). [Own translation]

Moreover, the participants pointed out several aspects which are needed in a standard, such as measurement methods, performance requirements and certification. Furthermore, a standard need to contain information about installation, charging, and the dimensions of the battery. Additionally, descriptions of how to dismantle them and each actor's responsibility in the value chain must be part of the standard. Finally, the standard formation would have to include continuous improvement and updating of the standard.

Furthermore, another aspect that was mentioned in the workshops was the importance of considering profitability not only for the company but also for the customers. In line with this, one participant mentioned that it is important to consider the aspects that are important to the customers before stating a definition and implementing a standard (WS2).

4.4.2 Consensus

The creation of a standard can be described as a voluntary process in reaching common characteristics, this aspect was reflected in the discussions and responses. To encapsulate the common characteristics requirements, the category Consensus was formed. As mentioned previously, the participants indicates that there needs to be a unified understanding of definitions, concepts, and specifications to be able to form a standard. One response has expressed that there needs to be a form of agreement between the most important manufacturers and governments at a global level to be able to reach acceptance as well as create a harmonised roll-out plan. Furthermore, one participant pointed out that it therefore is crucial that actors in the supply chain are willing to initiate the work to create a standard for the batteries (WS1). In line with this another participant also mentioned that it is important that the big manufacturers collaborate to create a suitable standard, which can bring advantages for the companies as well as customers and environment (WS2).

“"When we look at standardisation, we must ask ourselves: What does the industry want? What do the manufacturers want? How big are the manufacturers and what power do they have to set guidelines for the market? What drives standardisation in our case?” (WS2). [Own translation].

During the workshop discussions, several participants countered with “*Is standardisation demanded by our customers?*”. Creating a standardised truck battery would lead initially to higher costs, as stated before, and the participants are therefore meaning that it is important to make sure that the customers are willing to buy the trucks even with a standardised battery.

4.4.3 Circularity

Integral to the sustainability of battery standardisation would be a life cycle perspective. The battery needs to be designed from the beginning to have thoughts on the battery’s next step in the value chain after its use in electric trucks. Whether that is ease of adoption in a second-life application or ease in recovering the critical materials within the battery. This is crucial since the entire idea of using electrified trucks is to ensure reduce environmental impacts. The responses which related to a life cycle perspective were grouped together and given the name Circularity.

4.4.4 Technology Maturity

A visible cluster among the responses was the category Technology Maturity, meaning responses which related to battery technology and its current and future development. One concern that several of the participants mentioned both during the workshops as well as in the online form, is that battery technology today is not mature enough for standardisation to be realised. Several of the participants highlighted that a lack of technical maturity as a hindrance to the creation of a standard (WS1, WS2). One of the most common statements regarding battery technology was *“batteries need to reach a technical maturity*”. During the workshops one participant commented that the process of standardisation in other types of products often comes later in the process, when the pace of development has slowed down (WS1, WS2). Therefore, several of the participants pointed out that the current battery technology is too immature to be standardised.

One important aspect mentioned by one of the participants regarding the implementation of standards, is the importance of remembering that batteries will continue to develop during the upcoming years. It is therefore of importance to note that continuous development of standards would be necessary to meet new demands as highlighted by the following quote: “*Don't forget that even though the principles of LI batteries have been the* *same for the last 100 years there might be a development of battery/ energy storing cells in the future with other demands."*

4.4.5 External party

The category External Party relates to the standardisation requirements regarding the need for an external party and the need for some kind of compliance structure mentioned by the participants in the workshops. If the different battery designs on the market are to converge into one or a few selected designs, then an external and neutral decision board must decide on what a battery standard would look like. Otherwise, there is a risk that unfair advantage is given to some manufacturers in relation to others based on their current design, *"In order to function effectively, a standard must be competition neutral." (WS2)* [Own translation].

Furthermore, the participants pointed out the need for some kind of structure to ensure compliance with the standard, possibly a global organ with the aim of ensuring compliance, audits, and maintenance of regulations. Moreover, the participant highlighted that the automotive industry might need to learn from the case of charging cables in the EU, if no consensus can be reached between the actors in the industry (WS1). Another participant also stated that it might be of importance that regulations are set since there is a risk that the company has a one-sided perspective. The participant therefore points out that legislation might be necessary and that it needs to be more about solving environmental issues (WS1).

4.4.6 Summary

From this part of the empirical findings, it can be said that there are several aspects which are required to create and implement a standard of a heavy-duty electric truck battery. Some of the aspects mentioned by several participants were, for example, the importance of having a clear definition of the battery level and the area of standardisation as well as the need of technical maturity of the product. The requirements that were mentioned by the participants and included in this part of the empirical findings are summarised in Figure 16 below.

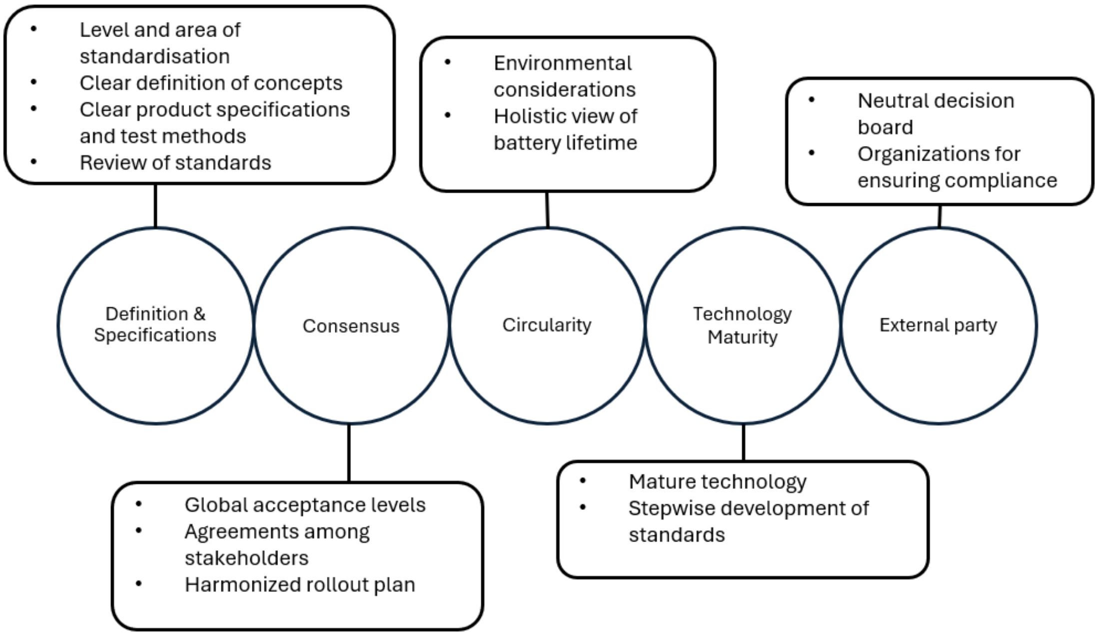

Figure 16. Illustration of the Standardisation Requirement Categories and their Individual Datapoints

5. Analysis and Discussion

In this chapter, the analysis and discussion of the empirical evidence will be dealt with together with the literature on the subject areas. The chapter consists of three main parts: the empirical analysis of opportunities regarding standardisation, the analysis of battery level standardisation and the analysis of circular supply chain structures. The first two sections answer research question 2 and the last section answers research question 3.

5.1 Empirical Analysis

The first part of the analysis begins with how the standardisation opportunities align with the standardisation challenges. Furthermore, this first part will analyse how the identified opportunities contribute to finding solutions to the identified variety of problems presented in the empirical findings. Most of the analysis in this part is made only concerning the empirical findings, however, in some parts of the analysis, the findings are connected to previous research. This part of the analysis will analyse the first part of the second research question, *managing variety: a) How does standardisation address the identified variety problems?*

5.1.1 Standardisation Opportunities and Challenges

To analyse how standardisation addresses the battery variety problems, the standardisation opportunities and standardisation challenges were first put in relation to each other. The specific opportunities are illustrated in Figure 12 and the challenges can be seen in Figure 14. To get an easier overview of the categories, Table 5 was designed. On left hand side, the identified challenge categories are presented, and the top-side presents the identified opportunity categories. When the table was designed, all the individual opportunities and challenges were systematically assessed in pairs, one-by-one. The categories which were considered to have a substantial influence on each other are marked with a full black circle. This indicates that the category had opportunity-challenge pairs where they might either align or conflict. The categories that could have an influence on each other are marked with a half circle, meaning that the opportunity-challenge pairs had the potential for alignment or conflict, though it was not given. The categories with opportunity-challenge pairs that were considered to not influence each other are marked with a white circle and will not be further discussed in this chapter. By using Table 5, it was possible to identify if, and to which extent the challenges weaken the opportunities.

Table 5. Influence between Standardisation Opportunities and Standardisation Challenges

Challenges \ Opportunities	Production Efficiency	Business Potentials	Unified Technology	Reduced Lock-in Effect	Value Chain Improvement	Improved Reuse & Repurpose	Environmental Gains
Production Changes	●	●	○	○	○	○	○
Business Risks	●	●	◐	●	◐	◐	○
Hinders Innovation	○	◐	●	○	○	○	○
Value Chain Adaptation	◐	●	○	○	◐	●	○
Environmental Risks	●	●	○	◐	○	○	●

○ : No apparent influence ◐ : Could have influence ● : Substantial influence

From Table 5 it is possible to see that the categories *production changes, production efficiency, business risks and business potentials* influence each other. All these categories are assumed to have the largest influence on the OEMs since they are related to their productions and business setups. When analysing the different aspects of each category it can be said that, for example, the standardisation opportunities within the production efficiency might be hard to reach since the battery standard might bring challenges related to the production as well. To better understand which standardisation opportunities that could be reached regardless of the identified standardisation challenges a further analysis will be made. Moreover, some of the identified opportunities will bring benefits for some of the actors in the value chain, however, there might be challenges related to these opportunities that will create difficulties for other actors. Therefore, it is crucial to also understand how the opportunities and challenges are affecting the different stakeholders, in both positive and negative ways. Without the understanding of stakeholder perspectives, it is hard to motivate if a standard would bring opportunities that are strong enough to justify the implementation.

To further understand if the identified opportunities still can be reached even after considering the identified challenges, an analysis will be presented. In this analysis, all categories, both opportunities and challenges will be presented and discussed.

5.1.1.1 Production Efficiency

In the empirical findings, one identified opportunity was *production efficiency*. Within this category, the opportunities of producing *higher volumes*, *economy of scale* and *streamline the production* were presented. These opportunities will bring direct benefits for the OEMs and indirect benefits for the other stakeholders. However, concerns regarding the challenge category of *production changes* could weaken the opportunities. The standardisation challenge *effects on the production line* are assumed to be related to the risk of increasing the time in the station where the battery is installed into the truck. This could be a risk since the standard is considered to change the battery design and its preassembly, which will affect the flow in the production as well as line balancing. However, the increased volumes and streamlined production can be assumed to be valued higher. This is due to that changes in the battery design are assumed to not have a directly negative effects on the production. The changes in the design could be assumed to might also have a positive effect on the production, by making improvements on the line balancing. Since it is hard to determine if the changes on the battery design would have a negative effect on the production, the opportunities of reaching *higher volumes and streamlined production* are considered to still be strong. Streamlined production could still be achieved with a battery standardisation present, since it could simplify or ease certain steps in production. Moreover, the adoption of a standardised battery in production could lead to a need for updating competence in handling, installation, and safety procedures. However, the change of competence is assumed to have a rather small effect, since competence around battery handling needs to be updated for every battery generation.

The opportunity for *higher volumes* also risks being weakened by other challenges. Some of the challenges that were mentioned in the *business risk* category, which could have an effect, are *supply risks* and *renewed strategy.* These risks are connected to the OEM’s business. These challenges can be assumed to appear if materials that are critical to producing batteries experience disruptions in availability, for example in the case of semiconductors. However, even if these are risks for production, the battery standardisation itself is not assumed to increase this risk. This is due to the fact that the material that are used in production today possess this type of risk, since the materials are critical, and are therefore considered to not be a much larger issue even if a battery standard were to be implemented.

Furthermore, the *higher volumes* opportunity could be weakened by the challenge of *supply chain inflexibility.* Higher volumes would mean that there is an increased need for more capacity at suppliers, distributors, logistics providers and factories to handle the increased volumes. As a result, more investments could be needed, which reduces the potential profit of an increased production volume. However, since the OEMs are already moving towards EVs, there is a need to ensure that the supply chain can handle the increased volumes, regardless of battery standardisation. Thus, the supply chain inflexibility can therefore not be considered as a challenge with battery standardisation and will not have a negative influence on the possibility of higher volumes.

Furthermore, the *business risk* challenge that could weaken the higher volumes is *risk of short supply*. Regardless of if the OEM will buy the entire battery pack or if they make their own battery packs, there is a risk connected to material availability. Moreover, there is an *environmental risk* that the battery standard will *bring intensified pressure and need for specific resources*, which will be harder to find and to a higher cost. The risk of a short supply of material, will depend on how the battery standard is defined. If the standard does not specify which material to use, then it will not be more challenging than it is today, without the battery standard. However, it could also be discussed if a standard that specifies the materials will lead to an increased risk of short supply since it can be argued that the manufacturers today are, to some extent, using similar materials.

This analysis shows that the identified opportunities of standardisation, mentioned in the empirical findings, can be weakened by the identified challenges in different ways. It is possible to see in the analysis that the standardisation opportunity of increased volumes, also creates a lot of challenges. However, due to the reasons mentioned, the challenges are not strong enough to remove the opportunity of higher volumes.

5.1.1.2 Business Potentials

The *business potentials* opportunity directly impacting on the OEMs and contains of two specific opportunities, *increased market access* and *reduced costs*. A standardised battery would have a direct cost impact. The reduced cost will have a positive impact on the OEM, but also the customers that can buy the products to a lower cost. However, the cost reduction must be put in relation to the challenges of *production changes* such as the anticipated need for *investments, and the resources required to change the product design*. Investments could be needed if the battery technology that becomes the standard is far from the OEM's technology. Although the size of such investments is unknown, the OEM could still achieve profitability long-term from the sale of larger volumes and to some extent benefit from their already established technical competence. Moreover, the workload and time required to modify the product design to fit the standardised battery must be considered as well. However, the modification of design will have to be made once when the standardisation is accepted. The cost and effort of modification will thereafter not change more often than when standards change, which can be compared to updates between the generations that are performed today.

The literature mentioned that the OEM’s self-interest and willingness of keeping their competitive advantage is a challenge to standardised batteries for EVs (Dominish et al., 2021). The identified *business risk* challenges in the empirical analysis show that the OEMs are worried about losing their competitive advantage if a battery standard is implemented. Therefore, this business risk can be considered to hurt all the identified opportunities in the category business potential. Furthermore, as mentioned in the empirical findings, the business offering of Case Company is built on a high degree of customer adaptation which is why standardisation of batteries could limit the customer adaptation in this area and therefore hurt the company´s reputation. However, in the future the battery standardisation might make it possible for the company to provide customer adaptation on the batteries as well.

Within the *business potential* category, there is an opportunity of *increased market access,* meaning being able to reach out to more markets. This opportunity has to weight in the challenges connected to *hinders innovation and value chain adaptation.* All markets will not have sufficient charging infrastructure, which lessens the strength of the opportunity. Thus, there is a challenge in reaching more markets if there is a need for infrastructural investment in some markets. From this, it can be assumed that the opportunity, *increased market* *access,* will not be strong enough when putting it in relation to the lack of infrastructure in the new markets. Furthermore, a standardised battery might reach more markets in other regions, but risks being a *one-size-fits-all*. This means that there is a risk that the batteries that are designed to work well in on type of climate not necessarily are adopted to be suitable in another. The *supply chain adaptation* also requires new distribution channels and infrastructure for the end-of-life collection in each new market. There will be a risk of uncertainties of responsibility and ownership of the collection, and recycling process in markets in general.

Another challenge that was mentioned in the *hinders innovation* category was the *innovation constraints*. This challenge might not be connected to a specific opportunity; however, the risk of hindering battery innovation can potentially affect all standardisation opportunities. In the empirical findings, it was mentioned that the battery technology is not considered mature enough to realistically implement a standard. However, technology which is under rapid change or development can still be standardised. When handling products that are under rapid development, it is important to create a standard that does not limit the technological development (Brown et al., 2010). Therefore, that the battery and its technology still are under development are not a hinder to create a battery standard.

From the analysis, it is possible to summarise that the opportunity of business potentials faces multiple challenges. First off, the reduced costs can be diminished by investments in production as well as an increased workload from design changes. The biggest challenge would be any investment costs in relation to possible future sales. Secondly, increased market access is inhibited by insufficient charging infrastructure as well as distribution channels and EOL-collection structure. Particularly the EOL-structure will pose a challenge since it will change in different regions. In the end, business potentials are still an opportunity, but it is important to not undermine the challenges it brings with it.

5.1.1.3 Unified Technology

The *Unified Technology* category mentioned *simplified infrastructure development* as an opportunity in the empirical findings. Having a standardised battery used by all OEMs, can be assumed to make it easier to develop infrastructure, for example for charging. The infrastructure development is assumed to be simplified since it will enable finding a common solution to charge batteries regardless of the truck's brand. However, one challenge within *Hinders Innovation* that could weaken the opportunity is large investments needed to set up and develop the infrastructure. Although the challenge regarding the investments exists, it's assumed to have a small effect on the opportunity. Investments are assumed to be necessary to develop a charging infrastructure regardless of whether the battery is standardised or not. However, it can be assumed that the opportunity of *simplified infrastructure* might not be as strong after all since ongoing projects exist for charging infrastructure. Investment and collaboration between OEMs have been established for ensuring that the customers, regardless of which OEMs they have bought their trucks from, have the ability to charge their trucks. Volvo Group, Traton Group and Daimer Trucks have started Milence to install and operate a high-performance public charging network for battery electric heavy haulage trucks across Europe (Milence, n.d.). These collaborations have already been created to find new and common solutions, which is why a battery standard is considered to not be able to bring anything new to this. Due to the mentioned reasons, the development of infrastructure might not be more simplified with a standard since the development and collaboration already is in place. However, the simplification of infrastructure development can could be an opportunity for other types of infrastructure such as the EOL collection infrastructure.

Simplified access to and measurement of battery data was also mentioned as an opportunity for all stakeholders. The opportunity for the OEM can, however, be weakened by the *business risk* of hurting the brands' reputation. One potential risk for the OEM with the increased possibility to measure the battery data would be if the measurements show that the OEM's batteries are not in line with the battery standards or if they are worse than the competitors' batteries. For other stakeholders, the measurement of battery data would be beneficial since it reduces the risks throughout the value chain thanks to the knowledge of battery health as well as chemistry content which facilitates appropriate handling.

This analysis shows that there is a conflict between the ability to access data and the risks connected to the business. However, it can be said that both the simplified infrastructure development and the simplified access to and measurement of battery data will be opportunities. Therefore, the opportunity regarding unified technology is considered to be strong.

5.1.1.4 Reduced Lock-in Effect

One identified opportunity in the empirical findings was the *Reduced Lock-in Effect*. Within this category, *the ease of comparing product quality, lower entry and exit barriers for customers* and *the ability to exchange batteries* were mentioned as opportunities. From a customer point of view, battery standardisation is assumed to be a large advantage, since it enables them the ability to exchange batteries. Thus, they can decide on which battery that best suits their needs. Furthermore, the second-use actors could also benefit from the ability of comparing product quality, since they can then choose what battery is best for their requirements. However, from a business perspective, the ability to compare the quality can be considered to be a business risk. Competitive disadvantage is one potential risk for the business since the ease of comparing product quality makes it possible for the customer to identify how well the company´s batteries are performing in relation to other brands. In line with this, there is also a risk of damage to the brand image, if the OEM's batteries are performing worse than promised. According to the literature, brand image is an important factor when creating competitive advantage, which also means that the manufacturers need to manage the brands with care (Townsend et al., 2013). Furthermore, there is a risk that the ability to compare products can affect the OEM's business in a negative way since it will make it harder for the OEMs to keep loyal customers. Instead, the customers will have lower entry and exit barriers, when they can easily compare and switch to another brand if a better option appears. From this it can be stated that the OEMs will meet several challenges with the reduced lock-in effect, however, the customers will have a large advantage. Therefore, it is of importance to keep both perspectives in mind when looking at standardisation of the batteries.

Furthermore, another mentioned opportunity in the empirical findings was that *better products can be achieved at a lower cost*. However, this opportunity is not considered to be strong enough to be an opportunity since it is hard to state if a battery standard actually will be able to create a better product at a lower cost. An identified challenge was the *cost-cutting risk, leading to environmental effects*. The risk with cost-cutting could be that the cheapest option might have a negative effect on the environment. One potential negative effect could, for instance, be that the low-cost battery producer takes small initiatives to reduce their impact on the environment. With this in mind it can be said that it is of importance to take the environmental impact into consideration when defining the standard, which also were mentioned in the empirical findings.

From the above analysis, it can be stated that the battery standardisation will bring opportunities for the customers, however, it might at the same time hurt the OEMs. Therefore, the potential opportunities and challenges of battery standardisation related to the reduced lock-in effect can be considered to be a conflict between customers and the manufacturer's business. Furthermore, the analysis also shows that there is a conflict between the reduced lock-in effect and the impact on the environment. Despite these conflicts, it can be assumed that the opportunity of reduced lock-in effect can still be achieved through standardisation. From this analysis it can be said that customers, manufacturers, and the environment perspectives must be considered and weighted against each other to make the best decision regarding the battery standard.

5.1.1.5 Value Chain Improvement

Within the *value chain improvement* opportunity, one possibility is the *Simplified maintenance*. However, from an OEM's perspective, this opportunity is diminished by the *business risk* challenge. There is a competitive disadvantage in not having branded spare parts since it removes the income stream after the product has been bought. *Increased ability to create value* is another identified possibility within the *value chain improvement* opportunity. However, the possibility must be put in relation to the risk of a *one-size-fits-all solution*, which could hinder the possibility of increased ability to create value, since, as mentioned previously, there will be different requirements on the battery in different contexts and from different users. The opportunity of increased ability to create value can be considered to be quite unclear, and in combination with the risk of one-size-fits-all solution this opportunity is considered to be of less relevance and will therefore not be discussed any further in this thesis.

The analysis shows that there is potential for new ways to create value with the batteries. However, it is important to keep in mind, that the value chain might have to adapt to capture these opportunities. In the end, the opportunity is considered to be stronger than the challenges.

5.1.1.6 Improved Reuse & Repurpose

In the empirical findings, one identified opportunity was the possibility of *improved reuse and repurpose*. The opportunity can be exemplified through *simplified repair and remanufacturing*. However, the *simplified repair and remanufacturing* can be diminished by *business risks* such as competitive disadvantage in a similar way as mentioned in the section above. A conflict between the customer's ability to choose non-brand spare parts and the OEM's interest in providing branded spare parts emerges.

Simplified second use (repurpose) is another example of the opportunity to improve reuse and repurpose. However, the opportunity can be weakened by the challenges brought up in the *value chain adaptation* category. To actually achieve *simplified second use (repurpose),* there is a need to overcome the adaption of the supply chain and the risk of one-size-fits-all. The supply chain must be adapted to accommodate a more circular business model. It is not guaranteed that a standardised battery would create such a structure, even if it would enable *simplified second use* (repurpose). Lastly, a standardised battery could mean that the application in second use is easier to achieve since the batteries will have common characteristics. However, when introducing a standard there is a risk that the battery becomes a one-size-fits-all solution and not considering different regional- or user requirements.

From the analysis, it is possible to conclude that the opportunity for improved reuse and repurposing faces multiple challenges. Some challenges regard the conflict between customers' ability to choose and OEMs' self-interest. Other challenges relate to the evaluation and application of batteries after their first use. Although these challenges are present, the opportunity is deemed to be stronger.

5.1.1.6 Environmental Gains

Within the opportunity of *environmental gains*, the possibility to enable the *reduction of environmental impact* exists. The reduced impact can be put in relation to the selection of resources in a standard, which are not as devastating for the environment as other resources might be. However, as mentioned in the *environmental risks* challenge, the pressure on the selected resources increases, if the standard is specifying what metals and chemicals to use in the battery cells. There is a risk that the negative environmental impact just moves from one type of metal excavation to another. With the rising battery volumes in the near future, it is difficult to know whether the environmental impact will be reduced or not. On the other hand, not all materials for the increasing battery volumes need to be virgin. Instead, materials could be recycled from the *improved recycling processes*, a possibility which emerges as a consequence of standardisation of the battery cell, if the standard is on the chemistry content.

From the analysis, it can be argued that the increased pressure on selected resources could impact the environment negatively. The environmental gains could still be considered an opportunity, but it is important to keep in mind that the batteries still have a negative environmental impact. Moreover, the improved recycling processes are considered to be a strong opportunity, which is assumed to be reached with a battery standard.

5.1.1.7 Summary

From the analysis in the previous section, it can be stated that the standardisation challenges influence the standardisation opportunities in different ways. Not all standardisation opportunities and standardisation challenges will be equally beneficial or difficult for all stakeholders. The specific standardisation opportunities and standardisation challenges which are most applicable for a certain stakeholder will differ. Thus, if a standardisation of truck batteries were created, then the OEMs would benefit from new business opportunities, efficient production, simplified maintenance, and simplified repair. The OEM's customers would benefit most from the reduced lock-in effect, but there are also benefits from reduced battery costs, access to and measurement of battery data, simplified maintenance, and simplified repair. The second-use actors emerge after the batteries reach their EOL in trucks. This stakeholder group benefits the most from unified technology and improved reuse and repurpose as well as reduced lock-in effect. Lastly, the recycling actors benefit from improved recycling processes and access to battery data. It is important to not understate the benefit for the environment at large if the recycling process could be improved, as it would help reduce the demand of virgin critical material and help create a circular material flow. The different opportunities and which stakeholder group benefits from them can be seen in Table 6, based on the assessment from section 5.1.1. In Table 5, the opportunity-challenge pairs were evaluated one-by-one. However, in the analysis, it became clear that the stakeholders benefitted differently by the categories. A stakeholder analysis was then conducted for the opportunity categories, in which each opportunity was assessed based on the extent to which they would benefit the four stakeholder groups: OEMs, customers, second-use actors, and recycling actors. The outcome of the analysis can be seen in Table 6. The full black circles indicates that the stakeholder will achieve strong benefit(s) from the opportunity category, as it has the potential to directly bring benefits. The half circle indicates that the stakeholder could benefit from the opportunity category, however the benefits are not as clear or may be indirect. Lastly, the white circles indicates that the stakeholder does not receive any significant direct nor indirect benefits from a specific opportunity category.

Table 6. Stakeholder Perspectives on the Standardisation Opportunities

Stakeholders	OEM's Production Efficiency	OEM's Business Potentials	Unified Technology	Reduced Lock-in Effect	Value Chain Improvement	Improved Reuse & Repurpose	Environmental Gains
OEM	●	●	◐	○	◐	◐	○
Customer	○	◐	◐	●	◐	◐	○
Second-use Actors	○	○	●	◐	◐	●	○
Recycling Actors	○	○	◐	○	○	○	●

○ : No apperent benefit ◐ : Could be beneficial ● : Strong benefit

The standardisation challenges will be applicable to different stakeholders, like in the standardisation opportunities. The OEM's have the most substantial challenges in having to adjust their production and potentially losing some of their competitive advantage. Furthermore, innovation constraints due to standardisation were identified in the empirical findings to be a challenge, but with the literature it is possible to argue that this is in fact not contradictory. Moreover, the OEMs could face challenges in adapting their existing supply chains. The OEM's customers could face some challenges regarding their reduced degree of customer adaptations, which for many customers is the reason for choosing the Case Company. Regardless of stakeholder group, all actors could face the challenge with responsibility and ownership structure of the EOL-collection when standardising the truck battery. What challenges are applicable to each stakeholder group are possible to see in Table 7, based on the assessment from section 5.1.1. In the analysis it appears, as in the case of opportunities, that the stakeholders will be challenged in different ways by the challenge categories. Therefore, a stakeholder analysis was conducted for the challenge categories as well in order to assess to which extent the different categories challenges the four stakeholders. The outcome of the analysis can be seen in table 7. If a stakeholder receives direct drawbacks from a challenge category, then it is shown with a full black circle. When a stakeholders might face indirect challenges or the challenge are more difficult to assess, then a half circle is drawn. Finally, white circles show that a stakeholder does not face drawbacks from a specific challenge category.

Table 7. Stakeholder Perspectives on the Standardisation Challenges

Stakeholders \ Challenges	OEM's Production Changes	OEM's Business Risks	Hinders Innovation	Value Chain Adaptation	Environmental Risks
OEM	●	●	◐	◐	◐
Customer	○	◐	○	◐	◐
Second-use Actors	○	○	○	○	◐
Recycling Actors	○	○	○	○	◐

○ : No apperent challenge ◐ : Could be challeging ● : Substantial challenge

Introducing a standard for heavy-duty electric truck batteries is beneficial in some way for all stakeholders. As can be seen in Table 7, there are no major challenges for either second-use actors or recycling actors who are instead considered to gain advantages from battery standardisation. However, the same table shows that OEMs will face different challenges if a standard were to be implemented. Thus, it can be difficult to get the OEMs involved in battery standardisation work, if they do not see the full potential for a standardised battery, not only for themselves but for the other actor perspectives too. It is important to note that the benefits and challenges are not weighted. The half circles and the black circles show how their relative strength, but the weight of the black circles is not compared. The circles only show "where" benefits or challenges exist. For example, the benefit of *Environmental Gains* for *Recycling Actors* is assumed to be substantial as it is a cornerstone for reducing the adverse impact that batteries have on the environment, due to critical material extraction. Thus, it is crucial to think about the different perspectives if a standard would be implemented because they affect the actors in different ways. With the standardisation challenges and opportunities for the different actors in mind, it can be said that in order to achieve an entire CSC, there is a need for battery standardisation.

5.1.2 Addressing the Variety Problems with Standardisation

In this part of the chapter, an analysis is conducted regarding how the standardisation opportunities address the identified battery variety problems. This is done to answer to first part of the second research question, *managing variety: a) How does standardisation address the identified variety problems?* Some of the variety problems are unlikely to be handled by implementing a battery standard and will therefore not be brought up in this section. The opportunities discussed in the sections below are the ones that after the first part of the analysis still were considered to be strong opportunities with a battery standardisation.

5.1.2.1 Production Complexity

In the empirical findings, *production complexity* was an area where problems emerge today as a consequence of the battery variety. Within this area *cost inefficiency, line balancing and equipment diversity* were mentioned as problems. One of the identified standardisation opportunities was *higher volumes* in production, which creates *economy of scale*. This opportunity would emerge with the implementation of standardisation and thus handle the cost-inefficiency problem. The cost inefficiencies today exist because the processes cannot be standardised to mass produce batteries. By introducing a battery standard, the volumes could increase, leading to mass production which will improve the cost aspect. Furthermore, the cost reduction achieved by producing higher volumes is connected with the identified standardisation opportunity of reduced costs. The battery variety also causes issues with the line balancing since it creates an inefficiency. One opportunity with standardisation was that it enables a *streamlined production*, which indicates that it would improve the production environment. Additionally, it reduces unnecessary variety of equipment, which deals with the problem of equipment diversity.

Another mentioned variety problem in the empirical finding, is the *safety risk.* A standard of the battery would bring the opportunity *of simplified access to and measurement of battery data*, which will be a part in reducing the risk connected to safety concerns. The opportunity will make it possible to keep track on the status of the battery health and the energy content, which will make it safer to handle the batteries. Additionally, the risk reduction opportunity of battery standardisation will handle and reduce the safety risks that has been identified as a problem today.

5.1.2.2 Value Chain Complexity

Adding complexity for all actors was one identified problem regarding *complexity in the value chain* due to battery variety in the market. As mentioned in the previous section about production complexity, *the simplified access to and measurement of battery data* that a standardisation could bring would be a way to handle and reduce the complexity for the different actors. By having access to the data, the different actors in the chain will have full knowledge of the batteries and are therefore able to handle the batteries in a suitable way. This would particularly benefit customers, repurpose actors and recycling entrepreneurs. For customers, battery data and measurement data would enable ease of comparing product quality of the batteries.

The variety problem regarding *the complexity for all actors* would also be handled by the opportunities of *simplified second use (repurpose)* as well as *simplified repair and remanufacturing*. The large variety of batteries causes problems and complexity for different parts in the value chain. With the large variety it is, for example, hard to find a second-use solution that can be applied for all types of batteries. By implementing a standard this problem can be handled by enabling easiness in finding second-use applications. The same goes for the opportunity with repair and re-manufacturing, since the standard will reduce the variety and thereby reduce the complexity for the aftermarket.

Furthermore, a variety problem regarding *complying with regulations* was mentioned. This issue can partly be solved with battery standardisation and the specific opportunity, *enables environmental impact reduction*. By implementing a battery standard which includes required materials, it could become easier to complying with environmental regulations. If the battery standard considers any limitations made by environmental regulations, OEMs will comply with and implement regulations easier.

5.1.2.3 Aftermarket & Workshops

In the empirical findings, the area *Aftermarket & Workshops* is identified as a problem with the battery variety today. One of the identified problems is the *complexity of maintenance*, which can be handled by the opportunity *Simplified access to and measurement of battery data.* It is assumed that the maintenance is easier to perform if the status of the electric truck battery and its health is known. Moreover, one of the identified standardisation opportunities is the *simplified maintenance* which further reduces the complexity of maintenance today. The opportunity is considered to address issues related to *the lack of competence in the workshops* and *equipment diversity*. This is because it reduces the complexity of battery competence and the diversity of equipment when the number of battery varieties are fewer.

5.1.2.4 Reuse & Repurpose Complexity

Currently, variety problems exist within brands, due to generational variety, and across brands. Since there is no continuity between new and old generations of batteries within the same manufacturer, there exist *no generational compatibility*. Furthermore, since there is no coherence in the design or manufacturing of the batteries between brands, there is a *lack of replaceability* with the batteries. Both these identified problems exist in the *Reuse & Repurpose Complexity* category and can be solved by the opportunity of *increased modularisation*. Modularisation would mean that battery packs have a standardised size, power output and attachments to its application. In that scenario, batteries could be replaced across brands and generations. It would enable the customer's *ability to exchange battery, increase their number of options,* as well as *reduce their entry and exit barriers.*

Furthermore, increased modularisation would help solve the problem with *battery application complexity* in repurpose contexts. It would mean that actors, who create a business of repurposing truck batteries, can easily scale up or down their solutions and use the interchangeability of the batteries. Moreover, knowing the status and health of the battery is crucial for second use regardless of if the battery will be reused or repurposed. The standardisation opportunity *simplified access to and measurement of battery data* helps in separating which batteries should be reused or repurposed. It is likely that the applications for a repurposed battery may differ depending on how much energy content remains in the battery. Knowing the energy content of the battery and rigorously testing it also *reduces risks* with its handling and installation in an application. Thus, the problem of battery application complexity can be handled.

Lastly, the *Reuse and Repurpose Complexity* category brought up problems related to EOL-collection of batteries. There is a standardisation opportunity *of simplified infrastructure development*. It is possible that this also applies to the structuring of collection stations for EOL batteries. As of right now each manufacturer has to collect their own batteries, but with a standardisation it is possible that the automotive industry could find collaborative solutions for EOL-collection since there is no need to collect the own battery, making it simplified.

5.1.2.5 Recycling Complexity

Recycling complexity was one of the identified categories of variety problems. The complexity stems from the differences in chemistry at a cell level or the dismantling of packs and modules, which are designed in different ways. With a battery standardisation, one opportunity which could help solve this problem is the *simplified access to and measurement of battery data*. In particular, having access to the battery data as in its content, could enable a better sorting system at the recycling facilities and the ability to optimise the recycling processes. Furthermore, the knowledge of battery content is an important factor to reduce the risks that are associated with batteries. Particularly, safety risks will be reduced when batteries are to be recycled, by having a better knowledge of the specific content. Different energy content in batteries requires different handling processes to ensure safety, however, the knowledge of the battery content is often inadequate in the recycling facilities.

The inconsistency in knowledge about the battery content is not the only problem for the recycling facilities. The battery chemistry differences at the cell level also result in inefficient recycling processes due to process of separating the content, but battery standardisation in this parameter could *enable improved recycling processes*. Having the same chemistry in battery cells, could mean that recycling facilities optimise their processes for a certain kind of chemistry, leading to higher quality of recycled materials at a lower cost. Gaining better quality materials at a lower cost is crucial for creating a sustainable, circular battery value chain.

5.1.2.6 Diverse Technologies

In the empirical findings, *Diverse Technologies* was identified as a category when discussing battery variety problems. This category both drives the problem and is the cause of the other consequential problems. A standardisation of batteries would enable *ease of comparing product quality*, which would be beneficial if there will still be a chemistry difference. A standard would include performance requirements which customers then could use as a foundation of comparison. Furthermore, if the standardisation specifications regard the battery cell level, then there is the standardisation opportunity of *enabling environmental impact reduction* by banning certain resources. There could still exist chemistry differences, but the resources with the most adverse impact can be avoided. Lastly, it can be stated that the largest positive influence for the recycling would be if the standard were to be set on the chemistry.

5.1.2.7 Summary

This part of the analysis was performed to answer the first part of the second research question, *managing variety: a) How does standardisation address the identified variety problems?* From the analysis, it can be stated that the battery variety problems can in several cases be addressed by the implementation of a battery standardisation. In the end 14 of 22 variety problems were addressed by 11 standardisation opportunities. Table 8 show the connection between standardisation opportunities and the different variety problems. Note that the table only brings up the opportunities which have been identified to address variety problems and that several variety problems are handled by more than one opportunity, thus are mentioned several times. From the analysis, it can be seen that a battery standardisation would address the problems related to second-use and recycling of the batteries by enabling the same setup for all batteries. Furthermore, it shows that a battery standardisation can handle problems related to the OEMs since it will enable simplified maintenance and repair which in turn will potentially increase customer satisfaction. Moreover, standardisation will also have the ability to handle the cost inefficiency problems that exists today because of that the batteries cannot be produced on larger scales. By introducing a standardisation of heavy-duty electric truck batteries, the volumes of the same battery type could increase, which would improve the cost aspects for the OEMs.

Lastly, it was seen that the customers could be facing problems with changing batteries due to the variety between the generations of batteries. Changing the batteries to a newer generation in an electric truck thus becomes more difficult. By implementing a standard for the batteries, these issues will be handled in the future. To summarize, a battery standardisation would be good from an environmental point of view and enabling creation of a circular value chain.

Table 8. Shows the opportunities that are assumed to be handling the variety problems.

Standardisation Opportunities	**Variety Problems**
Higher volumes	Cost inefficiency
Streamlined production	Equipment diversity Line balancing
Simplified access to and measurement of battery data	Safety risk Adding complexity for all actors. Complexity of maintenance Differences in chemistry at a cell level
Simplified second use (repurpose)	Adding complexity for all actors
Simplified repair and remanufacturing	Adding complexity for all actors
Enables environmental impact reduction	Complying with regulations
Simplified maintenance	Complexity of maintenance Lack of competence in the workshops Equipment diversity
Increased modularisation	Lack of replaceability No generational compatibility Battery application complexity
Ability to exchange battery	Lack of replaceability No generational compatibility Battery application complexity
Simplified infrastructure development	EOL-collection of batteries
Enable improved recycling processes	Inefficient recycling

5.2 Standardisation Design

As the empirical findings pointed out, one crucial requirement to creating and implementing a battery standard is to define which level of the battery should be standardised. This part of the analysis will focus on which battery level the standardisation should be made on, to bring the most benefits and answers the last part of the second research question, *managing variety: b)* What battery level should be standardised to bring opportunities for all key stakeholders? A simplified illustration of the different battery levels can be seen in Figure 17.

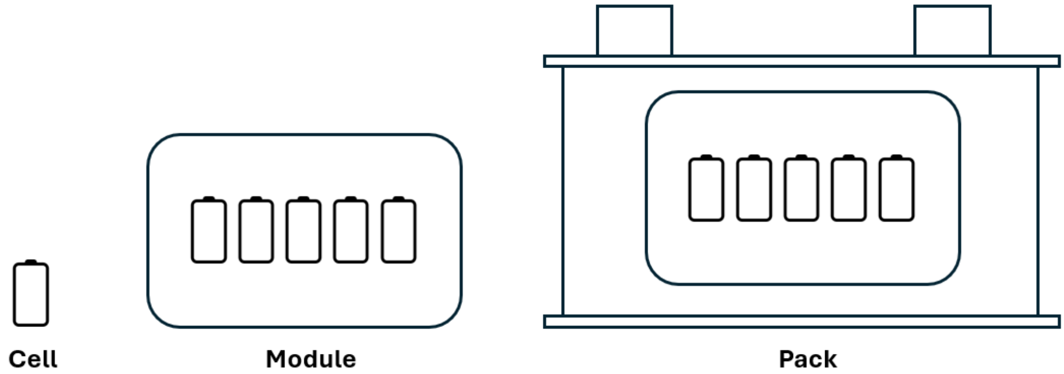

Figure 17. Illustration of the Battery Levels of a Heavy-duty electric truck Battery.

It is important to not only see the number of opportunities that can be reached, but also the importance of the areas that are receiving improvements. In the following analysis, the different battery levels and the stakeholder perspectives will therefore be analysed more in-depth to get an understanding on which level that achieves the biggest opportunities.

5.2.1 Pack

From the identified standardisation opportunities, most benefits were applicable on a battery pack level. To standardise on a pack level could mean that size, shape, and attachments would be determined. However, as mentioned in the literature the design of the battery pack is dependent on for example which battery cell is used (Engel et al., 2019; Warner, 2014). This could mean that even if a standard would be implemented on a pack level, the cell and its variations need to be considered when designing the standard. Looking at it from a business perspective, standardisation opportunities such as *higher volumes, streamlined production, increased modularisation, reduced costs, and simplified maintenance,* can be reached. The opportunity regarding *higher volumes* can be reached with standardisation, which enables an increased volume. The increased volume would in turn improve the cost aspect for the company. This opportunity is considered to be reached at a pack level since the battery pack influences the production. Furthermore, streamlined production will be reached by standardisation on the pack level by ensuring that all electric trucks have the same design on their batteries, which will ease the process of installing the batteries in the electric truck. At this level, the opportunity with increased modularisation plays a significant role. The modularisation would mean that battery packs have a standardised size and connection to their application which will improve the efficiency in the production.

The battery standardisation and the increased modularisation are also important for the ability to facilitate easier maintenance, as the packs can easily be replaced or upgraded without necessitating extensive customisation. The simplified maintenance can also be considered to be a benefit from a customer perspective since it likely reduces the waiting time for maintenance and reduces the costs. As mentioned in the literature, cost is one of the most important aspects for customers (Menon Economics, 2018). Moreover, the simplified maintenance can be assumed to enhance the longevity of the electric truck, which fosters greater customer satisfaction as well as loyalty to the company.

Furthermore, the customers will also benefit through reaching opportunities such as *ease of comparing product quality, lower entry and exit barriers for customers, and the ability to exchange batteries.* All these opportunities enable the customers to make their own choices to a greater extent, change batteries if they do not reach expectations and improve the lifetime of their electric trucks.

Lastly, circular value chains are achieved through the creation of *simplified: second use (repurpose), reuse, re-manufacturing* and *access to and measurement of battery data.* By standardising the battery on the pack level, the easiness of finding new applications or re-manufacturing the batteries after use would increase for the different actors. Reusing and repurposing the batteries are, according to the literature, the most sustainable alternatives for handling the batteries (Ahuja et al., 2020). Furthermore, if the packs are standardised, then access to and measurement of battery data will be simplified by having common methods and tools. In the literature, it was mentioned that the inconsistency of testing the health of batteries increases the costs of the processes as well as creates problems regarding the reuse of batteries since it is important to know the health of the battery before reusing it (Dominish et al., 2021). Being able to correctly evaluate battery data would easier enable second-use actors to decide what application is fitting for the battery. This would improve the circularity of the batteries since it enables an extended lifetime for the batteries instead of becoming waste, which is of importance due to the limited availability of critical materials (Ahuja et al., 2020).

To sum this up, standardisation on the pack level will have benefits for both the business and the customers as well as the creation of circular value chains. However, this analysis shows that from circular value chain perspective few environmental benefits are achieved if the standard is made on the pack level.

5.2.2 Module

On a battery module level, there were fewer identified opportunities which were applicable compared to the pack level. However, there are still opportunities for achieving a higher level of circularity. If a standardisation was introduced at a battery module level, then it would simplify the *access and measurement of battery data* as well as *simplify the re-manufacturing*. These two opportunities combined would lead to an easier reuse and repurpose of battery modules. A standardised module would probably also mean increased production efficiency for one of the Case Company´ facilities, where the cells are placed into the modules. A standard would make this process simplified, since it will reduce variety which in turn makes it possible to increase the volumes, leading to reduced costs. Furthermore, standardisation on the module level is also considered to be beneficial since it makes it possible to remanufacture the batteries in a simplified way. If the module were to be standardised it would enable the replacement of a module if one of the cells is of poor quality.

The module's function is to protect the battery cells from, for example, dust (Gerlitz et al., 2021). With this in mind, it can be argued that the main reason for having a module is to keep the cells safe. Furthermore, with the focus on cell safety, a standard on a module level could lead to a *risk reduction* since workshops will likely have to dismantle the pack and expose the modules when conducting troubleshooting. A standard of the module could be a possibility, but it is also considered to be irrelevant to create a standard of only the module in itself, since it is dependent on the two other levels. The module might be suitable to standardise if other levels are standardised as well. It is possible to discuss how a standardisation of the module level can be carried out, without standardizing the cell or pack level. As mentioned in the literature, the module is depending on the choice of battery cells (Windisch-Kern et al., 2022). Furthermore, as mentioned in section 4.4.1, the module level is dependent on battery pack design. The difficulty in achieving standardisation opportunities at this level could relate to the fact that modules are an aggregation of cells, without it having a stand-alone function as the battery pack. Additionally, battery design trends might mean that the module level disappears entirely (Pampel et al., 2022), making a standardisation of this level redundant.

5.2.3 Cell

At the battery cell level, the most distinct opportunities lie within the business perspective and circular value chains. If a standardisation of battery cells was introduced, then it would enable the production of *higher volumes* of cells, resulting in a *reduced cost* per cell. The combined benefit would result in a lower cost per battery pack as well, thus benefiting the business perspective. The higher volumes are considered to be achieved regardless of whether the standard would include specifications on form, size, power output or chemistry of the battery cell or not. Furthermore, a standardisation on the cell level would enable *risk reduction*. If the standard were set on the chemistry of the battery, it would increase the knowledge about the specific chemistry characteristics and risks. As mentioned in the literature, it is important to ensure that the batteries operate within certain safety boundaries (Gerlitz et al., 2021). Since it is risky to handle the batteries and especially the cells, this knowledge can in turn enable better care and handling of the batteries. Lastly, a cell standard could lead to *simplified access to and measurement of battery data* which would further strengthen the *risk reduction* by understanding the capacity and health of the battery cell.

The standardisation opportunities from a circular value chain perspective lie in the *simplified second use (repurpose)*, *enabling of improved recycling process* and *environmental impact reduction*. However, it should be pointed out that these opportunities depend on the definition of a cell standard. If there exist chemistry differences, then the strategies for second life become more complex (Chirumalla et al., 2024). Moreover, the recycling facilities have the biggest challenge in recycling different kinds of battery chemistry in the same process (Dominish et al., 2021). Furthermore, it is costly to separate the different materials from each other (Dominish et al., 2021). This adds additional problems connected to that a lot of different chemistries can be used that requires different setups. This means that a cell standard would have to include specifications on the chemistry to reach the opportunity to enable improved second life and recycling. Likewise, it could be said that it would bring the opportunity to reduce environmental impact through banning certain resources. Then a standard would have to include what resources to use or approve the use of. If a standard does not contain these parameters, and instead focuses on form, size, and power output, then these circular value chain opportunities will not be realised to a larger extent.

In the end, there has been a lot of scepticism about creating a battery cell level standardisation, particularly if it regards the chemistry. The standardisation is too tightly intertwined with the uncertainty of what chemistry will evolve into the dominant one and what the development of entirely new chemistries will look like. Furthermore, the OEMs are seeing the cell and its chemistry as the most important part to be able to have a competitive product.

5.2.4 Summary

This part of the analysis was conducted to answer the second part of RQ2, *Managing variety: b) how could a standard be designed to bring opportunities for the key stakeholders?* To find on which battery level a standardisation would bring the most benefits but also the most important ones, the battery levels were analysed in relation to the different stakeholder perspectives. These perspectives were OEM, Customer, Second-use Actors and Recycling Actors. The outcome of the analysis can be seen in Table 9 below, which shows on which level of the battery that the different actors will benefit from a standardisation.

Table 9. Benefits from Battery Level Standardisation in Relation to Stakeholder Perspectives

	Pack	**Module**	**Cell**
OEM	+	+	
Customers	+		
Second-use Actors	+	+	+
Recycling Actors			+

From the analysis and as Table 9 shows, it can be concluded that a standard on the pack level would bring the most opportunities from all three aspects, business, customer, and environmental perspectives. A module level standardisation would give benefits for the OEM and the Second-use Actors. However, to be able to reach the maximum environmental opportunities from standardisation, as recycling, it is necessary to standardise on the cell level. To be able to reach improved recycling it is necessary that the standardisation is in regard to the battery cell chemistry in particular.

Table 9 shows that different levels of battery standardisation would bring benefits for different stakeholders. A standardisation of the cell level would bring the most benefits to the environment. As can be seen in the literature, it is crucial to find solutions for extracting the materials from the batteries, since they are critical (Chirumalla et al., 2024; Tankou et al., 2023). To be able to solve the circular flow of materials and ensure that they can be used in the future, a standardisation on the cell level can therefore be necessary. Furthermore, it is important to highlight that the OEMs will benefit from an improved recycling process, as they require critical materials and constantly extracting virgin materials will increasingly become a problem. In a more near future, the most probable benefits for the OEM's business and customers would emerge from standard on a pack level. In the literature, it was stated that if a standard is not on both pack and cell levels in combination, problems connected with the handling and transportation of batteries will increase the costs and reduce the willingness to recycle (Thompson et al., 2020). With this in mind, it can therefore be hard to state which of the standardisation levels alone will bring the most benefits, even if it could be said that the cell level would bring the most value in the creation of a circular supply chains of batteries, since it brings benefits both for recycling as well as second-use. Thus, it might be argued that a standard on a cell level would be most beneficial since it gives a large change and improvement for the environment.

It should be noted that creating a battery standard is not an easy task. Regardless of whether the standardisation focus is on the battery pack, module or cell, there will still be a need for clear definitions and consensus amongst stakeholders, as indicated by the empirical findings, section 4.4.2, regarding standardisation requirements. If the battery cell level is to be standardised to solve both second-use and recycling issues, then the technology maturity will be a big issue to overcome. If the battery pack is standardised then there will be an increased pressure to have a holistic view of the battery lifetime, so that the batteries are not sent to recycling if they can be used again. Regardless of standardisation level, it is important that a standard includes a battery life cycle perspective to make sure that second-use and recycling is not neglected by the OEMs. Although the empirical findings brought up several factors which will affect the standardisation process, it is not an exhaustive list. There could be more factors at play to realise a battery standardisation.

5.3 Circular Supply Chain Structures

In the third part of the analysis, a standardised battery pack and cell will be put in relation to circular supply chain structures. The two levels, pack, and cell will be examined since they were considered to be of most relevance for standardisation and would bring the most opportunities. Here CLSC will be compared to OLSC in the context of standardisation of truck batteries. This section will answer research question three, *how could a circular supply chain for heavy-duty electric truck batteries be designed to achieve benefits for all key stakeholders?*

5.3.1 Circular Supply Chains Through Closed-Loop

The purpose of a closed-loop is to return the product in its entirety, while recovering that value within the control of the same chain (Govindan et al., 2015). For the Case Company such a CLSC could be created by recollecting their batteries and finding second-use possibilities internally, or by sending their batteries for recycling to recollect material for the production of new batteries. A simplified illustration of how such closed loop could be structured can be seen in Figure 18. In the analysis, the cell- and pack-level are analysed together as many characteristics of CLSC is similar regardless of the battery level. However, it should be pointed out that the main difference will be in the value recovery focus.

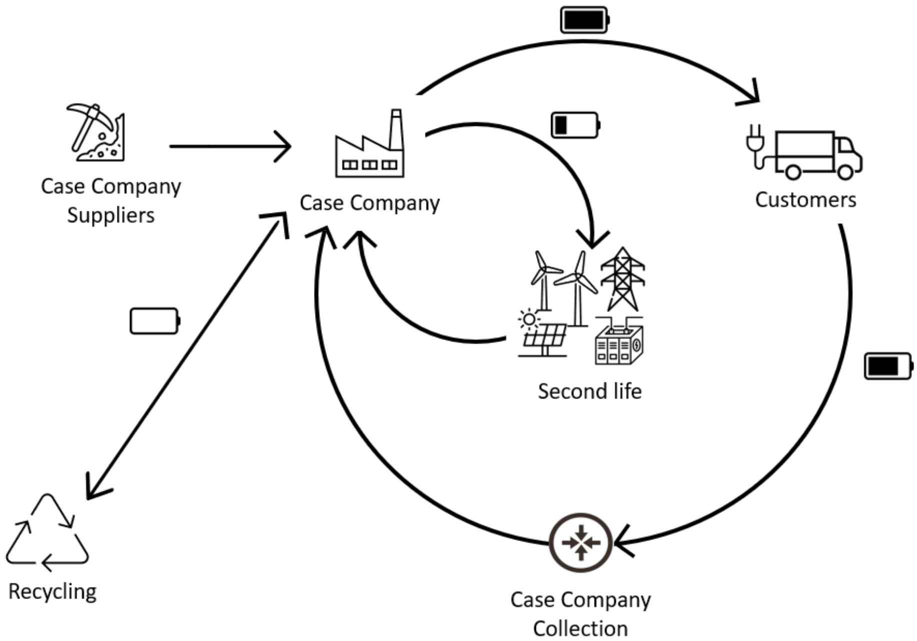

Figure 18. Illustration of a Closed-Loop Supply Chain in the Context of the Case Company

For an electric truck OEM, a CLSC would mean that the battery pack is the focus of value recovery, and that the collection of the battery pack would be organised by the OEM themselves. There are benefits connected to recovering the battery pack. From an environmental point of view, there is an incentive for the manufacturers themselves if they have to handle their battery packs because then they need to think about disposal and reuse from the start. However, this could be the case for the battery standard as well since it can be argued that a standardised battery pack might already include the lifecycle perspectives as well as reuse and disposal in its definition. Another benefit of recovering the battery pack, within the OEMs supply chain, is that they have a high economic value. To not collect the batteries, would open up for others to obtain value from their materials as well as get insight into their product design. The battery packs might not bring a lot of value after use for the truck producer; however, the OEM could use the batteries for their other products or sell or rent them out to other applications, and thereby increase their profits. Currently, clear battery ownership and inter-industry partnerships with the OEM seem to benefit second-life applications (Chirumalla et al., 2024). However, it is important to point out that the literature emphasizes these aspects without battery standardisation in mind.

The benefit of a standardised battery cell is the material recovery of critical resources if the battery pack is too degraded for second use. Although a CLSC has a primary product focus, the closed-loop enables OEMs to reutilize the critical material from their own batteries. If less virgin material must be extracted, then it will result in less strain on the environment. Moreover, there is a need to adhere to sustainability regulations where there is a need to have a certain degree of recycled material in the products (European Parliament & Council, 2023). By having a CLSC, in combination with a standard on the cell level, the OEMs can comply with these requirements without having to purchase recycled material from other actors. Furthermore, it would mean that OEMs would have to collaborate with recycling facilities to enable the conversion of battery packs into recycled materials. However, if the cell chemistry is not standardised, then the recycling facilities will experience problems when it comes to recycling in an effective way as well as making it hard for them to know which materials they are extracting (Dominish et al., 2021). As of right now, the recycling processes cannot achieve a high enough quality on the materials to be used again in truck batteries (Dominish et al., 2021)

When it comes to handling dangerous goods at EOL, a CLSC has been deemed as a good solution (Tavana et al., 2022). In the literature, it was mentioned that the handling of batteries can be risky. This is true for the battery pack and the battery cell, although the most potent danger lies in the cell level. The battery pack acts as a protective cover, but to remanufacture or recycle the battery packs, then this cover will be dismantled, and the safety risks increase. Electric truck batteries are considered a dangerous good since they possess a risk of explosion, electrocution, and leakage of battery liquids to name a few. These risks are expected to increase as the battery ages and is exposed to excessive usage. Thus, it is crucial that the batteries are handled with care and consideration to the environment and human health. One of the benefits of a CLSC is that fewer actors will collect and manage the batteries. It reduces the risks of not properly following the safety guidelines. If the OEM produces batteries, it is possible to argue that they possess a lot of knowledge of the batteries and competence to handle them, while third parties might not have that extensive knowledge, leading to an exposure of safety risks.

It is simple to establish a CLSC since it does not involve a large number of other actors (Kabir et al., 2021). However, as stated in the literature, a setup of CLSC requires a lot of investments (MahmoumGonbadi et al., 2021). In the market today, OEMs are trying to implement this type of setup with an CLSC, for example by investing in battery production facilities to create their own batteries. This implementation requires large investment for the OEMs, especially since this type of implementations are out of the core function of the companies. Furthermore, investments will also have to be made to ensure the collection of truck batteries at their EOL, which the OEMs need to establish on its own. Thus, it is possible to argue that one of the standardisation opportunities of reduced cost will be consumed by the investments needed in the CLSC. Therefore, CLSC might not be the best solution if a battery standard were to be implemented.

In a CLSC, the OEM bears the responsibility of managing the batteries. The benefit of managing a CLSC is, as stated before, that it is easier to establish since it does not require a lot of other actors. Furthermore, from an environmental perspective if the OEMs are forced to take responsibility for their batteries, then the collection does not risk becoming neglected. If the collection does not work well, then governments can put pressure on a specific actor. This approach can be seen presently in the Battery Regulation (European Parliament & Council, 2023), which forces companies to take responsibility for their batteries even after they have left production. Since it forces the OEMs to collect their batteries, the OEMs have bigger incentives to think about the EOL-phase from the start. With the CLSC the entire responsibility of managing and collecting the batteries is on the OEMs, and to ensure that they are taking responsibility, regulations are set. Since there is a need to force the companies to act, it can be questioned if the OEMs want to have that responsibility, or if there is a better way to structure the collection.

5.3.2 Circular Supply Chains Through Open-Loop

The purpose of an OLSC is to take advantage of materials and components, rather than focusing on product recovery (Berlin et al., 2022). OLSC could be created, for the Case Company, by allowing other companies to perform the collection of their batteries and finding value for the batteries in other industrial contexts. A simplified illustration of how such open loop could be structured can be seen in Figure . The OLSC has similar benefits for the pack- and cell-level, except for the value recovery focus.

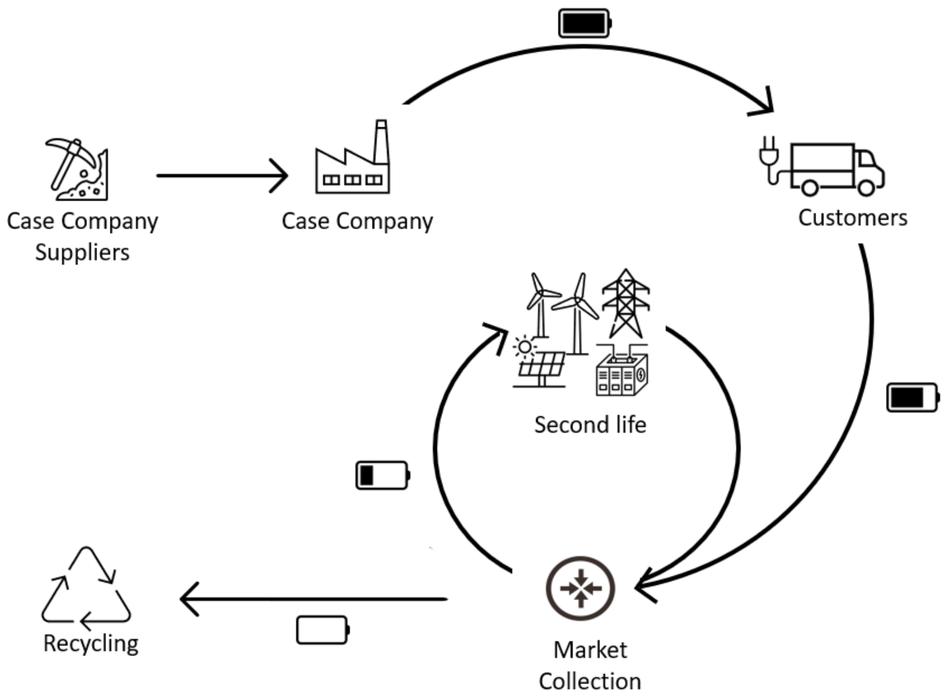

Figure 19. Illustration of an Open-Loop Supply Chain in the Context of the Case Company

Since OLSC has a material recovery focus, this could indicate that it would be more beneficial to standardise, for instance, the battery cell when using an open-loop. The benefit of using an OLSC in combination with a standardised battery cell, is that the recycling process can be improved. According to the literature, the materials that are extracted by recycling today are not of enough high quality to be used in battery production (Dominish et al., 2021), which is why this perspective can be considered crucial. In an OLSC, battery recycling can reach higher volumes and with an improved recycling process, it can potentially lead to becoming less expensive. Furthermore, to have the same chemistry in all batteries, which can be achieved with a standard on the cell level, would enable a more effective recycling.

A standardised battery pack in combination with an OLSC on the other hand, could be considered a weakness. One of the opportunities of a standardisation of the battery pack is to enable simplified second use, which is more in line with a product recovery focus. Even if the focus of the open-loop by definition is to recover the materials and components, it does not mean that the flow cannot be designed to handle the second use. One challenge with using OLSC in combination with standardisation of pack level is that the manufacturers have no incentive to take recycling into account when designing the products like they might do when they handle the entire flow by themselves. To not have the ability to disassemble the battery after use in mind can create difficulties for others, however, if a battery standard were to be implemented these types of issues would be handled.

In an OLSC, a diversity of different actors are in control of the system, and are working on creating as much value as possible for the product during the entire life cycle (Kalverkamp & Young, 2019). Thus, OLSC also opens the ability to create new entrepreneurs in the chain who can develop new solutions on how to handle, recycle and reuse the products, which would be beneficial for the entire industry. Looking at the standardised battery on both a pack and cell level, this setup and the creation of new innovative actors would be beneficial to be able to reach a higher level of circularity for the batteries. This would be beneficial regarding the ability to create good solutions for second use, and the standardised battery pack is an important part in doing so.

Furthermore, the creation of new entrepreneurs is also beneficial for the standardised battery cell since it enables to find solutions on how to recycle more efficiently to enable the reuse of the materials.

One of the most mentioned challenges was the innovation constraints and that the innovation of the battery might be hindered by a standard. However, the OLSC would probably bring benefits to OEM, by enabling open innovation and improvement of products (Kalverkamp & Young, 2019). This would mean that even if the battery pack is standardised, it can still be improved since the OLSC enables innovations on the standardised battery as well as the related applications. However, if a standard were introduced on the chemistry, it might cause problems related to the innovation of the batteries, since it might be more restricted.

In an OLSC, the collection responsibility is not on the manufacturer. This is because the materials are not returned to the manufacturer after use, and the flows are therefore disconnected from each other (Ning & Xin, 2021). This means that the batteries will be collected by various market actors, instead of the OEM. Having many actors means that there are safety risks to consider for the batteries. There will be several requirements that all actors who handle the batteries need to follow since they are considered dangerous goods. Thus, there would be a much higher need for safety guidelines and risk management for the actors working with the batteries. However, the risk of handling the entire battery pack is considered to be small, since the cells should be safe to handle as long as they are inside the pack. This means that this risk is small regarding the standardisation of the battery pack but increases on a battery cell-level. When it comes to the parts of the flow, where the packs are disassembled and the actors need to handle the modules respectively the cell, they are putting themselves at high risk, since they are unstable when disassembled. Batteries pose a risk to both the environment as well as for humans, making it crucial to disassemble them in a way that reduces the risk of these outcomes happening (Glöser-Chahoud et al., 2021). By having a standardised cell with specified chemistry, all batteries include the same content which enables the creation of common safety standards that apply to all batteries. The biggest drawback with having a market collection is the risk that the collection responsibility is left ambiguous. Thus, the battery management ends up fragmented, which could lead to partial collection and improper handling. However, one of the biggest benefits with a market collection is that the RSC can consolidate collection and transportation, which results in cost savings (Glöser-Chahoud et al., 2021).

Since there are many market actors active in an OLSC the investments needed to collect, reuse, repurpose and recycle the batteries are spread out. This would probably mean that the investments needed for the OEMs are lower than if they have full responsibility.

5.3.3 Comparison of Closed-Loop and Open-Loop

The closed-loop would mean that the Case Company will take their batteries back after use in trucks to find innovative solutions for the batteries or send them to be recycled for recollection of their materials. As mentioned in the earlier part the closed-loop means that the OEMs take the responsibility of the entire process. The same thinking was seen in the example of Coca-Cola and their universal bottles that after use are returned to them (Sudusinghe et al., 2024). For the Case Company, the closed-loop will have many opportunities since they can keep their resources within the company and ensure that they can get value out of the batteries even after they have been used in trucks. This is considered to be of importance since as mentioned, the batteries have a high economic value. On the other hand, it is hard for the company itself to manage all the different processes, which as mentioned also will mean large investments. Tesla, the car manufacturer, is one example of where closed-loops are applied (Tesla, n.d.). In the case of Tesla, they will handle the recycling of the batteries by themselves, which requires large investments. To do this will cause large cost for the Case Company, which can be seen as a disadvantage because a standard battery pack would reduce other costs in, for example, production. If a closed-loop were used in combination with a standardised battery pack, no change in the cost aspect would therefore be reached.

To instead implement an open-loop can be an advantage for the Case Company to keep the investment costs down and still achieve the reduced production costs. As mentioned, the OLSC would likely bring benefits to OEM, by enabling open innovation and improvement of products (Kalverkamp & Young, 2019). Being able to innovate and improve the batteries would be beneficial for the Case Company to ensure that they have a competitive product, that they can make a profit from, already the first time they are going on the market. However, an OLSC will mean that the batteries are managed and recovered by other actors, which could be seen as a disadvantage since it would mean that the Case Company is losing business potential in the second market. As mentioned in the previous section, implementing an OLSC for batteries will come with risks, since batteries are classified as hazardous products (Ahuja et al., 2020), which means that they need to be handled with care. Thus, using an OLSC requires that safety restrictions are set and that the batteries are handled with care in every single process to make sure that the batteries will be safe to use. However, from a sustainable point of view, an open loop might bring several benefits. These benefits could be achieved by the open structures' ability to create new entrepreneurs in the chain which can work with finding new ways to handle, recycle and reuse the products (Kabir et al., 2021; Kalverkamp & Young, 2019).

Comparing the two different set-ups of circular supply chains, reveal their strengths and weaknesses. Since the batteries contain a lot of energy even after use in the trucks (Chirumalla et al., 2024; Glöser-Chahoud et al., 2021), the reuse or repurpose part is considered to be of large relevance. This, as mentioned above, might be an obstacle to implementing an OLSC since the focus is, according to the literature, on material and part recovery. Furthermore, the importance of collaboration between actors in the chain is another aspect of the OLSC that needs to be managed and could cause problems in its creation. Moreover, from a safety point of view, a CLSC can be considered to be better to ensure that the batteries are managed safely and correctly. From these aspects, a CLSC can therefore be considered more favourable. However, it can be assumed that large investment costs are anticipated, for example, to recycle the batteries within the company, if an OEM chooses to implement a fully CLSC (MahmoumGonbadi et al., 2021). On the other hand, fewer investment costs are expected in an OLSC set-up since several actors will take part in the supply chain to find second-use applications. The collection will have higher requirements of collaboration since more actors are involved, however, if successful could lead to reduced costs by consolidating collection and transport (Glöser-Chahoud et al., 2021). Furthermore, by involving more actors the recycling process can improve. Particularly the efficiency of recycling battery cells is the strongest benefit of an OLSC, as seen from an environmental point of view. However, the Case Company is today using a closed-loop approach there they are using their newest business area to find second-use applications and manage material recovery.

Open-loop and closed-loop supply chains can be designed in many ways. A CSC is not necessarily strictly open-loop or strictly closed-loop. (Berlin et al., 2022). As can be seen from the comparison above, both chains could be beneficial but also create problems in different areas. Both the closed- and the open-loop supply chains solve circularity problems. However, the CLSC has been argued to not focus on creating sustainability (Kalverkamp & Young, 2019), since the focus of the CLSC is on how the individual OEM gains from an economic perspective rather than creating sustainable solutions. On the other hand, OLSC enables a greater focus on societal benefits, which from the point of view of this thesis work could be more beneficial. The OLSC concept, however, does not open up strong benefits for the OEM and having the perspective of the manufacturers is important. The manufacturers are one of the drivers in the transition to sustainable, electrified vehicles. CLSC on the other hand gives the OEMs a lot of control in their supply chain and enables them to capture as much value from their products as possible. However, CLSC does not enable as much second-use innovation in the supply chain as an OLSC would. The comparison of the two circular supply chains is summarised in Table 10. In the table the different aspects are not weighted, however, the EVs was introduced to reduce the environmental impact of transportation, and therefore the focus on environmental issues is considered to be of larger importance.

Table 10. Main characteristics of the Circular Supply Chain Setups

Closed-loop	Open-loop
• Enable the OME to have control. • Easier capturing of business value • Fewer risks of handling batteries • Increase the need for investments. • The focus is on the OEM	• Enables open innovation to find new solutions. • Capturing environmental value more easily • Divides the investments between the actors in the chain. • Might mean more risks when managing the batteries. • The focus is on the environment

The initiative to transition from combustion vehicles to EVs came from environmental concerns, but with time the batteries have created other environmental issues, which must be taken care of to achieve full sustainability. From this analysis, it can be seen that an OLSC could be the most beneficial from a societal and environmental point of view, by enabling new entrepreneurs on the market to create value from the used electric truck batteries. It is, however, important to remember that an OLSC would lose the OEM's ability to reuse the products in their own production, which could be considered as negative from the business point of view. CLSC on the other hand, enables the OEM to capture as much value as possible from the batteries, albeit with the disadvantage that the societal benefits are not as strong. To have a long-term sustainable transition to an electrified automotive industry, it can be considered to be crucial that the OEMs benefit from the circular supply chains. However, since the flow should be created to ensure the sustainability of materials it is important that the second use and recycling perspectives are not lost in the process, which is why OLSC might be a better alternative for creating full circularity. Currently, with the battery variety today, the CLSC can be considered to be the best setup, since the batteries are managed by the respective manufacturers. In that way, the battery variety is separated into manageable flows. However, the implementation of battery standardisation opens up the ability to instead use an OLSC setup. With the implementation of battery standardisation, the variety of batteries will be reduced, which makes it easier for the second-use actors to manage batteries from different producers. It could also be argued that a battery standardisation might not achieve its full potential if a CLSC setup is used, since the standard is assumed to bring benefits related to second-use and recycling. If the loop is closed, then these actors will be limited in their product and process innovation since OEMs will have control over the entire loop. In the end, to obtain the highest degree of circularity an OLSC should be chosen regardless of which battery level is standardised. The automotive industry will in the near future face a huge volume of EOL batteries in combination with a supply shortage of critical materials. Thus, solving the recycling issues, to create an entirely circular flow, will be of utmost importance.

6. Conclusions

The aim of the study was to investigate how the standardisation of heavy-duty electric truck batteries could reduce the variety of batteries and thereby contribute to full circularity. To achieve this the study investigated which problems that are arising for different stakeholders as a consequence of the variety of electric truck batteries on the market. Furthermore, through the study it was possible to identify if these problems could be addressed through standardisation. To get an understanding of this it was crucial to understand which opportunities and challenges a standardisation of heavy-duty electric truck batteries would bring for the stakeholders as well as on which level of the battery should be standardised to achieve those. By studying these aspects, this work contributes to finding a circular flow of heavy-duty truck batteries.

Three research questions helped reach the aim. The first research question was formulated as: *What type of circular value chain problems arise today due to heavy-duty electric truck battery variety?* Through this study, 22 value chain problems which were divided into six categories based on their characteristics, could be linked to the large variety of heavy-duty electric vehicle batteries on the market. The six categories of identified problems were: *Production Complexity, Value Chain Complexity, Aftermarket & Workshops, Reuse & Repurpose Complexity, Recycling Complexity,* and *Diverse Technology*. These identified categories and the belonging problems, which have arisen because of the variety of batteries on the market, are one of the most important aspects of this work. Out of all battery variety problems in the six categories, the problems regarding inventory complexity, second-life application and EOL-collection were the most prominent. The battery variety problems have built a foundation for understanding the importance of the remaining work and importance of creating circular flows.

The second research question was twofold in managing variety. The first part was formulated as: *Managing variety: a) How does standardisation address the identified variety problems?* The study can conclude that the introduction of a battery standard for electric trucks would deal with the identified variety problems to a great extent. The analysis showed that 14 of the 22 identified variety problems can be solved by ten of the identified opportunities that a standard would bring. The variety problems are solved in different ways depending, for example, on in which part of the value chain that the problem appears. Some of the variety problems would be addressed through more than one opportunity and these problems are therefore assumed to be addressed by standardisation to a large extent. Since the variety problems exist in the different parts of the value chain; different stakeholder groups will benefit from the battery standardisation in different ways. A battery standardisation would, for instance, streamline production processes which would manage the identified problems, *equipment diversity, line balancing and safety risks*. The standardisation would also manage problems by improving battery compatibility across applications and facilitate the use and management of batteries. The result from a battery standardisation would promote the sustainability and circular economy of heavy-duty electric truck batteries.

The second part of the research question was formulated as: *Managing variety: b) What battery level should be standardised to bring opportunities for all key stakeholders?* Which level of the battery that should be standardised to bring opportunities varies among stakeholders. The different levels can be associated with different opportunities and challenges for the different stakeholders. To bring the most opportunities for the OEM a standardisation of the pack level would be beneficial. This level would also be beneficial for the OEMs customers as well as the second-use actors since it enables the possibility of exchanging batteries. From an environmental point of view, a standardisation of the pack level would bring less opportunities compared to a standardisation of the cell level. A cell level standardisation would reach more environmental opportunities since it enables improved recycling and extended life for the batteries. Furthermore, the cell level would also bring opportunities for the OEMs, since it would decrease the costs of battery production. However, to reach these benefits the standardisation needs to be on the battery chemistry to be effective. With this it can be said that a standardisation of the battery cell and/or the battery pack would bring opportunities for the different stakeholders. It is possible today that a standardisation of the pack level or cell level would enable circular value chains by facilitating second use and recycling. However, it is clearer that a cell level achieves a closed circle of materials.

The third and last research question was formulated as: *What circular supply chain structure for heavy-duty electric truck batteries would be more appropriate to achieve benefits for all stakeholders?* It is possible to conclude that the most appropriate circular supply chain structure to achieve benefits for the OEMs, OEMs' customers, second-use actors, and recycling actors would be an OLSC, since it creates a strong alignment with battery standardisation. CLSC on the other hand has the benefits of a high degree of OEM control, safe handling of batteries and an OEM focus on product recovery. However, a battery standardisation in combination with CLSC will not be able reach its fullest potential. A battery standardisation together with an OLSC would create a common foundation on which market actors could base product and process innovation on. Therefore, the most appropriate CSC structure for heavy-duty electric truck batteries would be an OLSC.

6.1 Implications of the study

The results in the empirical findings and the following analysis in this study has the potential to make a significant impact on the future. Currently, the automotive industry and society face a lot of different problems like energy supply risks, limited supply of critical resources, a large battery variety in the market as well as inadequate reusing and recycling of batteries. Being able to manage these issues is crucial to achieve sustainability.

From the literature and the empirical findings, it can be seen that the OEMs prefer CLSC, because they can recover the battery's high economic value and sees the part as strategically important. Additionally, the OEMs are being forced by regulations to handle batteries responsibly, making CLSC the most advantageous setup. Although CLSC creates circularity, there is a built-in limitation, as the flow only considers the OEM's own batteries. On the other hand, OLSC opens up a circular value chain configuration on a larger scale, which will become significantly more important as the entire automotive industry transitions to electrification and increases the EV volume. The transition started as a way to protect the environment and create more sustainability compared to the usage of fossil fuels. With the transition, the entire automotive industry faces the challenge of switching to a material-intensive value chain in a world where there is already a limited supply of critical materials. Thus, solving a circular material flow will be crucial. From the study it is possible to argue that it is mainly the OLSC setup that offers an efficient solution to the material circularity, especially at the cell level.

From the study, it is possible to see that circular value chains require a certain level of standardisation. In order to open up the possibility for other actors such as customers, second-use actors, and recycling actors, to benefit from the batteries, there must be a reduction in battery variety. When the consumer batteries were standardised, it opened the possibility for the application market to grow. The growth of applications means that the number of equipment which could be powered by the consumer batteries increased. The same needs to be reached for the electric truck batteries, and thereby the heavy-duty electric truck batteries need to be standardised to allow the application market to grow. By this, the heavy-duty electric truck batteries can, for example, be used for energy storage, which was stated as a critical application. The industry should standardise the battery and instead allow applications to vary, instead of locking the applications and allowing the battery to vary.

Standardisation of batteries has during the workshops been met with scepticism because of the risk that the standard would inhibit the rate of innovation. The doubt is to some extent justified since the battery is seen as a strategic part for the OEMs and rate of the battery development has been rapid in the last decade. However, it can be pointed out that standardisation does not necessarily inhibit the battery innovation if the standard is developed to enable innovation. Instead, it would mean that the standard would have to be updated as new technology is made available.

6.2 Future Research

The exploration of heavy-duty electric truck battery standardisation has been conducted with both manufacturers and society (customers, second-use actors, and recycling actors) in mind. However, only the views and opinions of one manufacturer have been studied. Thus, in future research, it would be interesting to include the views and opinions of other manufacturers or even other actors like the manufacturers' customers, companies focusing on repurposing the batteries or recycling facilities. The inclusion of others' perspectives would lead to more reliable findings regarding the possibility of standardising heavy-duty electric truck batteries and the opportunity it can bring.

The study has identified a number of battery variety problems as well as opportunities, challenges, and requirements with regards to standardisation of heavy-duty electric truck batteries. The lists of identified categories in each area are not exhaustive nor have they explored the depth of each category. Thus, future research could further explore any chosen area or go more in-depth in any category. For example, the process for implementing a standard could be further researched and so can the aspect of recycling actors and what they would require in a battery standard specification. Another example for further research within the categories is to explore the business models for standardised electric truck batteries. In order to reach the greatest benefits of standardisation, modularisation is considered to be of importance. However, in this study this aspect has not been studied further which therefore could be of interest in future research.

During the thesis project, several interesting articles have been studied in the area of circular economy. Most of the articles have had the perspective of CSC, there the focus is mostly on the CLSC. However, one of the articles (Kabir et al., 2021) mentioned that companies could benefit of using an OLSC. During this thesis, the possibilities of using open-loop have been analysed, and it would therefore have been interesting as well as useful to have more literature on the application of the open loop concept and its opportunities from a business perspective.

The final future research recommendation regards the studied context. One of the delimitations of the study was to only investigate the context of heavy-duty electric trucks. However, creating a circular supply chain for batteries is not only important for electric trucks, but also for other electric vehicles like cars, construction vehicles, buses, or light- to mid-duty trucks. Thus, it could be of interest to study battery standardisation in these other contexts as well.

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Appendix

Appendix A – Workshop Questions

1. What is your title?
2. For how long have you worked within this field?
3. What problems do manufacturing companies (and your department, function) face today because there are different generations of batteries used in trucks?
4. What problems do society (e.g. customers, environmental aspects, other actors) face today because manufacturers create brand specific truck batteries?
5. What opportunities could a global standard of truck battery create for a manufacturing company (and your department, function)?
6. What opportunities could a global standard of truck battery create for society (e.g. customers, environmental aspects, other actors)?
7. What challenges could a global standard of truck battery cause for a manufacturing company (and your department, function)?
8. What challenges could a global standard of truck battery cause for society (e.g. customers, environmental aspects, other actors)?
9. What requirements would have to be in place for the creation of a global standard for a truck battery?

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