Master's degree thesis

LOG950 Logistics

Energy Transition and Circular Business Models: The Case of Repurposing Electric Vehicle Batteries in Retecho

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Preface

This paper constitutes my master's thesis in the Master of Science in Logistics program at Molde University College. Working on this thesis has been interesting and challenging, bus educational and rewarding.

I want to thank my research supervisor, Harald Martin Hjelle, who was always available if I had questions or problems related to the paper. His critical feedback has been crucial to this thesis.

Further, I want to thank the informants for taking the time to participate in this research. The insights and knowledge provided valuable contributions which were essential to completing this thesis.

Finally, I would like to thank my family and friends for motivating me throughout the semester, as well as the good memories I have made over my two years at Molde University College.

Molde 22.05.2023
Mathilde Vestøl Tjelta

Abstract

Purpose – The purpose of this study is to investigate how the repurposing of EV batteries can contribute to facilitating the ongoing energy transition and the implementation of circular business models. This study further aims at identifying the barriers related to implementing CBMs in a case company, and how these can be addressed to facilitate repurposing.

Methodology –An exploratory single case study of a Norwegian tech company currently developing solutions for repurposing EV batteries was conducted. Further, an integrative literature study was conducted to investigate how the repurposing of EV batteries can contribute to the energy transition. This study is a qualitative study where data were collected through semi-structured interviews, with the aim to obtain information and insight into this topic.

Findings – The empirical findings show that the repurposing of electric vehicle batteries can contribute to facilitating the energy transition through various factors that will contribute to the decarbonization of society. Further, the findings suggest the potential for circular business model implementation in the case company, but circular business models bring varying barriers to overcome for the case company. The barriers include finance, scalability, traceability, supply chain, and market. Still, several strategies are suggested to address these barriers for the company.

Limitations of the study – There are some identified limitations of this study. First, the research has limited itself to a single case study in the Norwegian market. Second, the number of informants is limited.

Practical implications – The energy transition will be essential to the decarbonization of society. Understanding how repurposing can contribute to facilitating energy transition and how the implementation of circular business models can enable repurposing is critical for understanding the value of repurposing electric vehicle batteries in the energy transition and circular economy.

Keywords – Energy Transition, Electric Vehicle, Lithium-ion Batteries, repurposing, Circular Economy, Circular Business Models

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List of Abbreviations

BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BM	Business Model
BMS	Battery Management System
CBM	Circular Business Model
CE	Circular Economy
EOL	End of Life
EU	European Union
EV	Electric Vehicle
IPCC	Intergovernmental Panel on Climate Change
KPIs	Key Performance Indicators
LIB	Lithium-ion Battery
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
PLE	Product Life Extension
PSS	Product-as-a-service
RQ	Research Question
SoH	State of Health

1.0 Introduction

This chapter contextualizes the topic of this study, encompassing the research problem that arises from the existing gaps and missing connections in the literature. Further, the research questions (RQs) are presented and justified, forming the foundation for the subsequent exploration of the study. Lastly, an overview of the thesis structure is provided.

1.1 Background of the Study

In recent years there has been growing pressure to contribute to the reduction of greenhouse gas emissions. The Paris Agreement, which was established in 2015, has a primary goal of reducing the increase in global average temperature to well below 2°C and ideally 1.5°C relative to pre-industrial levels (United Nations 2022a). The agreement was adopted to enhance the global response to greenhouse gas emissions and is a legally binding international treaty joined by 194 parties. A growing focus on the energy transition has emerged as a result of the urgent need to reduce climate change. The energy transition is a global shift towards cleaner and more sustainable energy sources, representing a significant shift from fossil fuel-based systems. It encompasses a set of technologies and practices targeted at lowering greenhouse gas emissions and mitigating climate change (IRENA 2022). The increasing demand has pushed several industries to undergo significant decisions in the form of introducing new technologies and infrastructures.

The transportation sector is one of the industries where mitigating the effect of climate change is crucial, and freight operations continue to degrade environmental quality by emitting harmful output, such as carbon dioxide emissions (Chatti 2021). Transport-related emissions are among the second-largest carbon emitters and constitute a threat to global warming. In 2021, the transportation sector accounted for 37% of CO2 emissions from end-use sectors (International Energy Agency 2022b). According to research, increasing the use of renewable energy consumption mitigate carbon emissions from transportation (Giannakis et al. 2020; Amin, Altinoz, and Dogan 2020). The transportation sector is developing and has the potential to make a significant impact on current environmental concerns by decarbonizing the industry with promising technologies. The electrification of transport modes is considered a major step toward the global sustainable energy transition and is essential for meeting the goal of decarbonization globally (International Energy Agency 2022c). Aiming at achieving decarbonization targets represents an opportunity to implement the Circular Economy (CE) and transition to low-carbon communities. This transition depends on expanding the supply of renewable energy production and the demand for electrification, particularly in the sector of transportation. Electrifying the transport sector necessitates an expansion in the production capacity of battery energy storage systems (BESS) to supply a growing share of electric vehicles (EVs) (Winslow, Laux, and Townsend 2018). Further, the successful implementation of the “green electro mobility” concept is heavily dependent on the green energy supply solutions of green EVs (Filote et al. 2020).

Along with the potential benefits of transitioning to electric mobility, there is a range of challenges with the increased utilization of batteries in EVs. Their hazardous nature raises concerns, and the anticipated increase in demand will intensify the need for raw materials, some of which might not be readily sustainable. As a result, there is a risk that some of the environmental gains from the transition to electric mobility may be diminished if there is no effective plan for the sustainable and safe management of EV batteries following the end of their first life in an EV (Ahuja, Dawson, and Lee 2020).

In a CE where resources are used as long as possible, managing end-of-life (EOL) for EV batteries is essential. The goal of a circular approach to managing the EOL of EV batteries is to recover the most value feasible from the batteries through reuse, repurposing, and recycling. The implementation of circular economy principles is of high importance to establish practical, commercially viable, and financially advantageous solutions in this area (Yang et al. 2021). Within the framework of a CE, one potential approach is the second use of batteries, which holds the promise of reducing battery waste and addressing future renewable energy storage needs (Kamath et al. 2020; Ahmadi et al. 2017). Nevertheless, the successful implementation of second-use batteries and the improvement of recycling rates necessitates overcoming various economic and technical barriers. Companies can surmount these obstacles by embracing Circular Business Models (CBMs) and integrating circular strategies, such as the utilization of second-use batteries, as integral components of their core business activities. CE strategies can potentially support retaining valuable and critical materials and reduce their environmental impacts according to Geissdoerfer et al. (2017), which makes it essential to increase the reuse and recycling of EV batteries to increase battery sustainability and establish a CE.

1.2 Research Problem

Recent academic literature on second-life applications for EV batteries focuses on the economic, technical, and environmental aspects of repurposing EV batteries (Zhu et al. 2021; Rallo et al. 2020; Cusenza et al. 2019; Ahmadi et al. 2017; Yang et al. 2021). Despite the research's valuable contribution towards understanding various aspects of EV batteries second life, it remains unclear to determine the role that repurposing of EV batteries will play in the decarbonization of society, particularly regarding the energy transition.

While some research has analyzed general drivers and barriers for CE strategies for LIBs (Hill et al. 2019), there is still a need to examine the variety of CE strategies being adopted and investigate the implementation of CBMs. Uncertainties remain, and there is much more to be studied about how such business models work in practice. Besides, there is a lack of research related to real-life applications for how CBMs can be implemented in the case of repurposing EV batteries. Implementing a business model approach could aid a clearer understanding of how to enable economically viable, circular use of EV batteries. CBM research related to EV batteries has been limited to the literature review, multiple-case studies, and Delphi studies (Olsson et al. 2018; Albertsen et al. 2021; Wrålsen et al. 2021). Since repurposing has yet to reach an industrial scale, these studies mainly report on pilot projects or simulations based on available data. Despite the large volumes of batteries that will be retired from EVs, industry-specific practices to enhance CE practice are still insufficient. Whereas Wrålsen et al. (2021) investigate the drivers and barriers related to CBM implementation for repurposing EV batteries, the research remains silent on how the barriers related to CBM implementation can be addressed.

This thesis aims to understand and gain knowledge about EOL management of EV batteries in the ongoing energy transition, and further an investigation of a company’s experiences with EOL management of EV batteries, CBMs, and barriers related to the CBMs. The desired outcome should help the case company to develop its CBMs as well as contribute to addressing barriers they might face in the repurposing of EV batteries. With the aim to address this, the following research problem is developed:

How does the repurposing of electric vehicle batteries contribute to the decarbonization of society, and how can circular business models be implemented to facilitate repurposing?

To investigate this, a problem statement with two components was constructed. First, there is a need to gain insight into how the repurposing of EV batteries can support the energy transition. This will be investigated from a broader perspective, whereas the investigation related to CBMs will go in-depth into a case company in the Norwegian context to analyze their current practices and barriers related to the implementation. Following the research problem, four RQs are developed and described in the next section.

1.3 Research Questions

To meet the research problem, the RQs are divided into broad- and narrow questions. The broad question aims to investigate how the repurposing of EV batteries can contribute to facilitating the decarbonization of society by investigating how repurposing can influence the energy transition. The narrow questions are developed systematically to investigate CBMs, identify barriers, and how these can be addressed to implement and develop CBMs in the repurposing of EV batteries through the empiricism of a case company. The RQs are proposed below, along with descriptions of how each relates to the research problem.

RQ1: To what extent could the repurposing of EV batteries for stationary energy storage systems facilitate the energy transition and contribute to the circular economy?

To meet the goals of decarbonization, there is a growing need for renewable energy sources as well as energy storage systems to store this energy (IRENA 2022). While some industry reports suggest the potential of repurposing EV batteries (Bashmakov et al. 2022; IRENA 2022), there is a lack of detailed understanding regarding the specific contribution this practice can play in the energy transition. Further, to implement a CE there is a set of strategies that should be implemented to successfully transition. The strategies for implementing a CE are commonly regarded as narrow, slow, make clean, and regenerate (Bocken et al. 2016; Fraser, Haigh, and Soria 2023), how can repurposing contribute to these strategies? The developed RQ aims to explore the importance and effects of EV battery repurposing in the context of the energy transition and circular economy. The aim is to understand how battery repurposing contributes to a more effective transition to renewable energy sources and the development of a CE. This RQ seeks to identify the potential benefits and opportunities associated with the repurposing of EV batteries for BESS to contribute to the energy transition and CE. The first RQ will be answered based on secondary data from an integrative literature review, with contributing aspects from the interviews.

RQ2: What are the solutions for managing the end-of-life of electric vehicle batteries in Retecho, and how do they apply to circular business models?

Every company has its business model (BM) which describes how they conduct business by illustrating how a company can create, deliver, and capture value (Richardson 2008). By investigating the solution for managing the EOL of EV batteries in the case company, this RQ focuses on analyzing how the solution for repurposing can align with CBMs. Although there is some research in the field of CBMs related to repurposing EV batteries (Wrålsen et al. 2021; Olsson et al. 2018; Albertsen et al. 2021), the objective of this RQ is to assess the extent to which the company's solutions conform with the principles and objectives of CBMs and previous research in the field. This RQ will be addressed based on primary information from the case company, as well as secondary information from the literature review.

RQ3: What are the barriers perceived at Retecho to the adoption of circular economy business models in repurposing electric vehicle batteries?

Despite the interest from practitioners, policymakers, and academics in the strategic management field, the widespread adoption and implementation of CE has yet to have happened. This can be related to a variety of barriers that businesses experience and perceive when developing and implementing CBMs (Vermunt et al. 2019). The main purpose of this RQ is to identify the specific barriers faced by the case company when it comes to implementing CBMs in the repurposing of EV batteries. The objective is to understand the barriers that hinder the company from adopting and effectively executing CBMs for repurposing EV batteries. By investigating these barriers, this research seeks to provide insights into the specific areas that need to be addressed and improved to successfully implement CBMs in the repurposing of EV barriers within the case company. Although there is previous research related to identifying barriers to CBM implementation for the case of repurposing EV batteries (Wrålsen et al. 2021; Olsson et al. 2018; Albertsen et al. 2021), it is relevant to investigate if the perceived barriers in the case company are corresponding or varying to previous findings. This RQ will be answered based on primary information from the case company, as well as secondary information from the literature review.

RQ4: How can these barriers be addressed to accelerate the transition towards a more circular system?

As previous research typically has investigated the barriers related to CBMs in repurposed EV batteries (Wrålsen et al. 2021; Olsson et al. 2018), this RQ seeks to explore the strategies that can be adopted to overcome the perceived barriers in the case company. Hence, addressing the barriers related to CBM implementation represents a research gap. Repurposing EV batteries currently present different barriers, making it crucial to identify solutions that may overcome these barriers to enable a circular system. Thus, the main purpose is to identify the most effective strategies for the company to overcome these barriers and facilitate the adoption CBMs for repurposing EV batteries for the case company. Like the RQs above, this RQ will be addressed based on primary information from the case company, and secondary information from the literature review.

1.4 Structure of the Thesis

This thesis is divided into six chapters as Figure 1-1 illustrates. The first chapter introduces the background of the study, leading to a definition of the research problem and related RQs to address the problem. The literature review in chapter two presents existing, relevant literature which assesses the energy transition, repurposed lithium-ion batteries, and the circular economy. Chapter three presents the research methodology applied for this study, while chapter four presents the results from the data collection. Furthermore, in chapter five the RQs will be discussed based on the findings presented in chapter four, and the literature review from chapter two. Additionally, a conclusion of the study is presented in chapter six and consists of a summary of the research, implications and limitations of the study, and suggestions for further research.

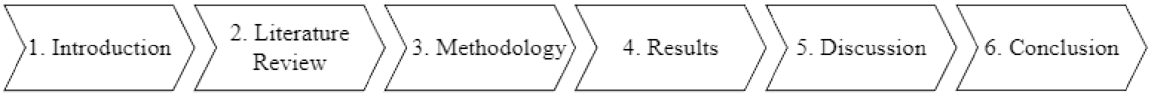

Figure 1-1. Structure of the thesis

2.0 Literature Review

This literature review is sectioned into five main parts related to the RQs. The first chapter seeks to address the energy transition and the electrification of the road transportation industry. The second part of the review includes an introduction of lithium-ion batteries, the repurposing of EV batteries to BESS, and the barriers related to repurposing. The next section provides an overview of the CE to establish general knowledge about the concept, as well as the concept of CE related to the repurposing of EV batteries. Further, CBMs and related barriers will be presented, as well as how these barriers can be addressed. Finally, the review connects CBMs to the repurposing of EV batteries by investigating existing literature on this topic.

2.1 Energy Transition

To meet the goals of the Paris Agreement related to pursuing efforts by limiting global warming to 1.5℃ by 2050, serious actions must be made (United Nations 2022a). The energy transition is a strategy for changing the worldwide energy industry from fossil-fuel-based to carbon-free and is perceived as one solution to the problem of global climate change (IRENA 2022). The ongoing transition to renewable energy is significant in that it is mainly driven by the realization that global carbon emissions need to be reduced to zero and that fossil fuels are the largest contributor to greenhouse gas emissions (United Nations 2022b). The global energy sector is shifting from fossil-fuel-based energy production and consumption systems including oil, coal, and natural gas, and toward renewable energy sources like hydro, solar, wind, etc. (Zheng et al. 2023; International Energy Agency 2022c). Renewables are set to become the dominant source of electricity worldwide in the long term. The growing share of renewable energy in the energy supply mix, the advancements of electrification, and developments in energy storage are initiatives that are accelerating the energy transition and have been considered globally to help minimize global emissions (IRENA 2022; International Energy Agency 2022c). To achieve the 1.5℃ scenario by 2050, IRENA (2022) developed six key performance indicators (KPIs) related to the energy transition as illustrated in Figure 2-1 which will be further elaborated upon.

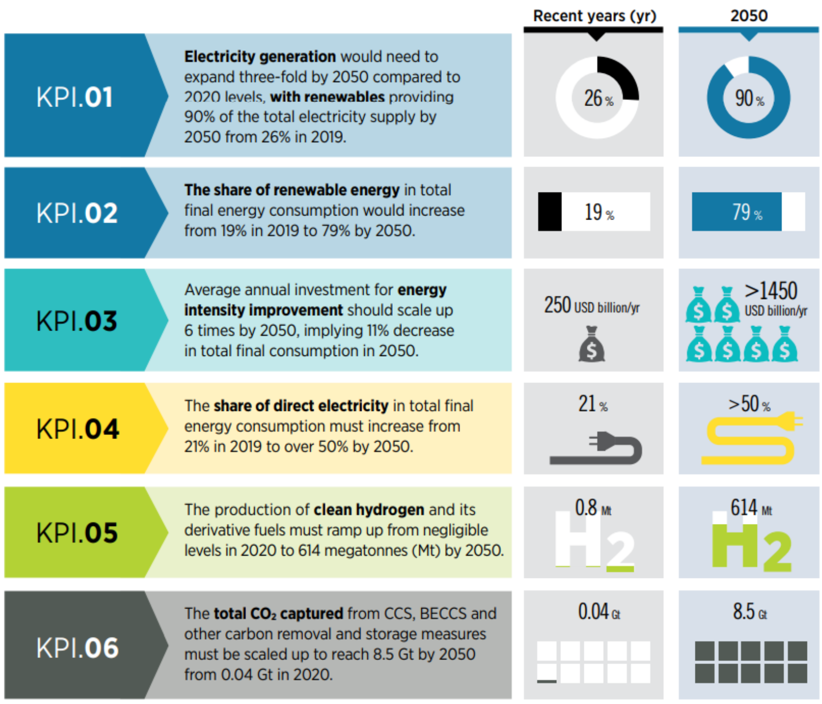

Figure 2-1. Achieving 1.5℃ Scenario by 2050: Key performance indicators. Retrieved from IRENA (2022)

KPI.01: Renewable Electricity generation development

The first KPI is linked to the increase in renewable energy power to supply electricity generation. To meet the 1.5℃ scenario, the electricity sector will need to be entirely decarbonized by mid-century. This will also be dependent on accelerating the deployment of all types of renewable energy technologies for generating purposes, such as wind, solar photovoltaic, hydropower, biomass, geothermal energy, and ocean-based energy. Wind and solar will drive the transition, accounting for 42% of total electricity generation by 2030. Whereas renewable energy accounted for 26.4% of global electricity generation in 2019, even faster deployment of renewable energy will be required (IRENA 2022). This is also emphasized in the World Energy Outlook report, where investments in clean energy are highly required, and the planned increase in global clean energy manufacturing capacity provides a leading indicator of the potential rapid increases in deployment (International Energy Agency 2022c). Furthermore, the Intergovernmental Panel on Climate Change (IPCC) report on climate change for 2022 stresses that the global energy system is the largest contributor to CO_2 emissions, which makes it essential to reduce energy sector emissions to limit global warming (Clarke et al. 2022).

Further, the increase of renewable energy in electricity generation indicates certain challenges due to the inherent variability and intermittency of renewable energy sources. As the demand for renewable energy expands, so does the need for energy storage systems to provide the flexibility and reliability of renewable energy. This highlights the need of developing and implementing energy storage technologies to successfully support the integration of renewable energy sources into the grid (International Energy Agency 2022c).

KPI.02: Increased share of direct renewable energy in the total final energy consumption

The second KPI focuses on the requirement for increasing the direct renewable energy deployment - such as bioenergy, solar thermal and geothermal - in final energy consumption such as transportation, buildings, and industry to decarbonize the sectors (IRENA 2022).

KPI.03: Increasing energy conservation and efficiency

The third KPI aims to increase energy conservation and efficiency. To attain the 1.5°C objective, energy efficiency must be rapidly and substantially scaled up (International Energy Agency 2022c), where energy efficiency will account for 25% of emissions reductions by 2050 (IRENA 2022). Energy conservation and efficiency require reducing demand for energy materials through a variety of actions such as energy efficiency, technical improvements, behavioral and process changes, and the implementation of CE strategies such as improvements in materials efficiency, reuse, and recycling (IRENA 2022). In the case of decarbonizing transportation, it will be critical to require new technologies, rigorous efficiency standards, and behavioral changes (IRENA 2022; Jaramillo et al. 2022).

KPI.04: Increasing electrification of end-users

The fourth KPI targets the electrification of end-users, which is estimated to contribute to 20% of emissions reductions by 2050 driven by the investments in electric transportation and the uptake of EVs. In future clean energy systems, electricity will be by far the most dominant energy carrier. Furthermore, electrification targets should be coordinated with plans for renewable energy deployment in the power sector. Such plans would encourage smart electrification solutions, such as EV smart charging and energy storage, which would provide flexibility to the power system (IRENA 2022). The electrification of transportation will be further elaborated upon in the next sub-chapter.

KPI.05 & 06: Clean Hydrogen and Carbon Capture

Accelerating the production of clean hydrogen and its derivative fuels is the fifth KPI, which will contribute to 10% of total emissions reductions by 2050. As global economies seek to achieve carbon neutrality, competitive hydrogen and hydrogen-derived fuels will provide an emission mitigation alternative for industry and transportation processes that are difficult to decarbonize through direct electrification. Finally, the sixth KPI is concerned with carbon capture, storage, and removal. Some emissions from fossil fuel consumption and industrial processes will remain in 2050. As a result, the implementation of carbon capture technologies, as well as carbon dioxide removal strategies, will be essential. Additionally, the development of technology capable of effectively extracting carbon dioxide from the atmosphere and allowing long-term storage will be critical to achieving negative emissions (IRENA 2022).

As the World Energy Transition Outlook (2022) demonstrates, there must be a significant acceleration of renewable energy, energy efficiency, electrification, hydrogen and derivates, as well as improvements in carbon capture and storage to achieve the path to 1.5℃ scenario. To accelerate the energy transition there is a significant focus on the electrification of the transportation industry which will be further elaborated upon.

2.1.1 Electrification in the transportation industry

The transport system is a major driver of climate change, accounting for nearly 40% of the emissions from end-use sectors, and consumes a quarter of total final energy consumption today (International Energy Agency 2022c; Jaramillo et al. 2022). The decarbonization of the road transport industry is an essential step in achieving global and national net-zero targets by the aims of the Paris Agreement (United Nations 2022a). A key factor in achieving this is the electrification of the transportation sector, where EVs have the potential to reduce emissions and energy consumption (IRENA 2022). The World Energy Outlook Report (2022c) asserts that electricity is the key substitute for oil-based fuels linked to transport final energy consumption by 2050, followed by hydrogen and biofuels. Further, the UN climate panel also emphasizes the electrification of road transportation as a strategy to decarbonize the transport sector (Jaramillo et al. 2022). Additionally, the Circularity Gap Report emphasizes that circular solutions for the transportation industry involve electrifying remaining vehicles to reduce the environmental impact and shift towards renewable energy (Fraser, Haigh, and Soria 2023).

In recent years, the transportation sector has seen a significant increase in the market for EVs. The total stock of EVs on the market worldwide exceeded 28 million units by the end of 2022 (Irle 2023), with a prediction that EVs will account for 80% of all road transportation activity by 2050 in IRENA’s 1.5°C Scenario (IRENA 2022). To demonstrate the uptake of EVs in the market Figure 2-2 illustrates the number of battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) on the market in Europe and Norway, as well as the current market share of EVs (European Commission 2023b, 2023a).

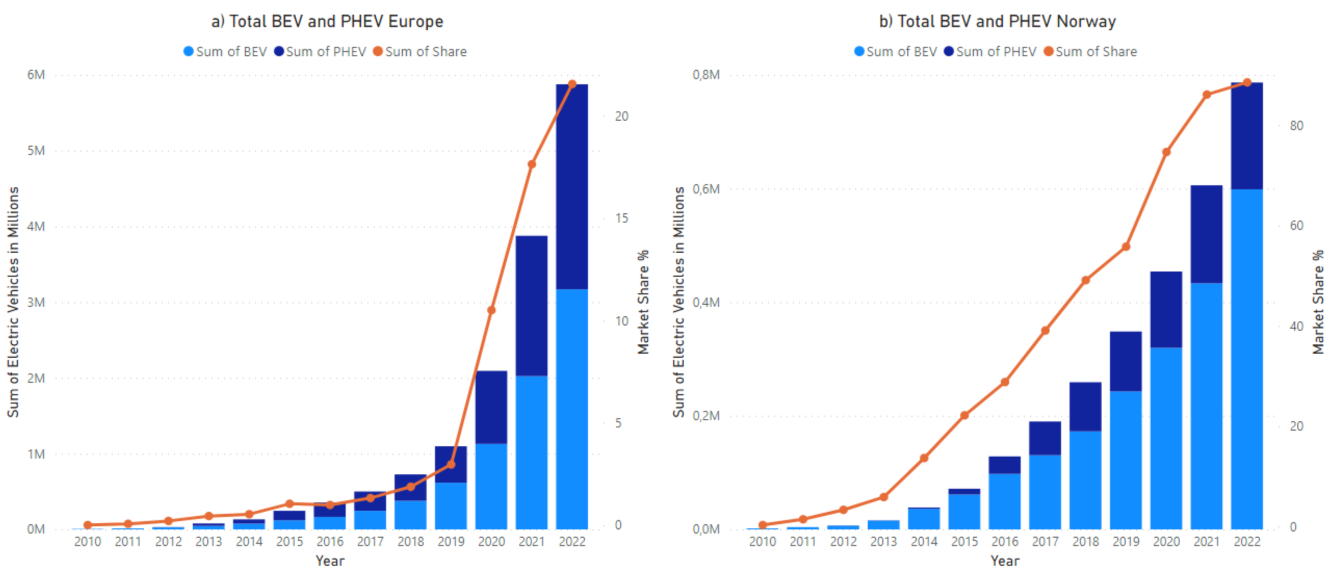

Figure 2-2. Sum and market share of BEV and PHEV in (a) Europe and (b) Norway between 2010-2022. Adapted from European Commission

The figure illustrates a market share of 21.56% of total registrations in 2022 in Europe and 88.52% of total registrations in Norway in 2022. In light of the increasing electrification of the road transportation industry, lithium-ion batteries are perceived as the dominant battery technology developed to fuel vehicles with energy sources (International Energy Agency 2022c; Armand et al. 2020; Ahuja, Dawson, and Lee 2020; Jaramillo et al. 2022; Abdelbaky, Peeters, and Dewulf 2021; European Commission 2022). This evolving battery technology will be presented further.

2.2 Lithium-ion Batteries in Electric Vehicles

The recent development of lithium-ion batteries (LIBs), which are the primary power source for electronic and electric devices, is rapidly being used to power EVs. It benefits from having a high energy storage capacity and a long cycle life (Armand et al. 2020; Ahuja, Dawson, and Lee 2020). The main components of an EV battery are the battery cell, the battery module, and the battery pack as illustrated in Figure 2-3 below.

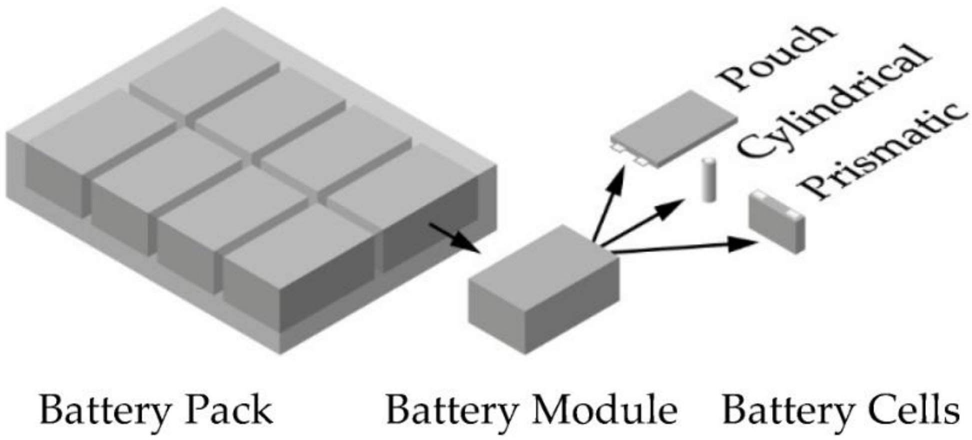

Figure 2-3. Battery assembly in an electric vehicle. Retrieved from Faessler (2021)

The lowest level is the individual battery cell. Depending on the original equipment manufacturer (OEM), different battery packs may contain cells of various types. Further, a battery assembly with a defined number of cells combined onto a frame is what makes up a battery module. The module shields the cells from external vibrations, heat, and shocks (Harper et al. 2019; Faessler 2021). The entire battery system installed in an EV is known as a battery pack and is made up of modules that are equipped with a battery management system (BMS) that makes sure the battery pack operates safely during both charging and discharging. By monitoring the pack and surrounding components connected to energy transfer, the BMS is in control of the electrical distribution to the application it is deployed in. To maintain optimal energy distribution and pack temperature in an EV deployment and enable the driver to operate a safe vehicle, the BMS is essential (Hou et al. 2019).

The four primary components of a LIB cell are the cathode, anode, electrolyte, and separator. Lithium-ions move through the electrolyte from the cathode to the anode when a LIB cell is being charged (Saifullah et al. 2022). When a battery is discharged, the lithium-ions flow in the other way and disperse electric energy to power the application it is being used in. The technology uses lithium as the main determining factor together with different metal oxides: Lithium Iron Phosphate (LFP), Nickel Manganese Cobalt Oxide (NMC), Nickel Cobalt Aluminum Oxide (NCA), and Lithium Manganese Oxide (LMO) (Armand et al. 2020).

2.3 The Life Cycle of Electric Vehicle Batteries

From raw material extraction to utilization in EVs, the life cycle of LIBs involves many processes. Figure 2-4 illustrates the life cycle of EV batteries which conceptually begins with raw material extraction, manufacturing of batteries, the operation in an EV, followed by return for collection, which can be referred to as the battery first-life (Hill et al. 2019; Faessler 2021; Wrålsen et al. 2021). Battery second life includes collection, reuse, and repurposing in less demanding applications (Hill et al. 2019; Zhu et al. 2021). Testing, battery-pack dismantling, and replacement of any broken modules or cells are all stages in the repurposing process. Depending on the reuse application, it can be essential to modify the battery pack's design or change the electronics and software (Reinhardt et al. 2019). Finally, when the battery can no longer be utilized it marks the EOL of the EV battery where the batteries are disassembled and recycled back into the economy as materials in the production of new batteries.

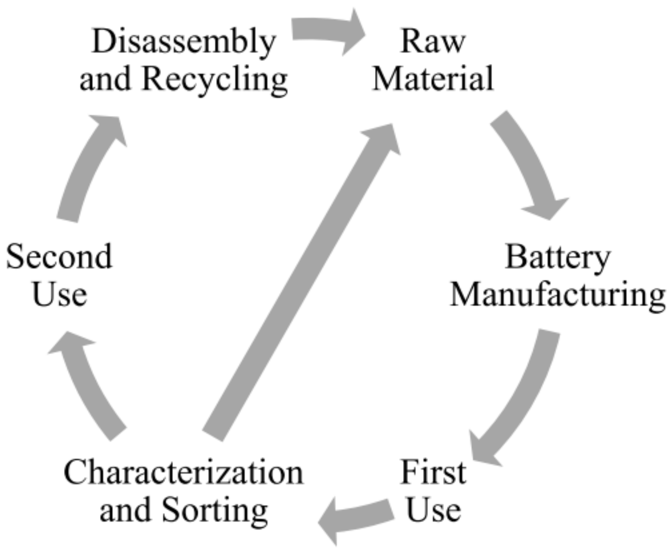

Figure 2-4. Life cycle of electric vehicle batteries including second use. Retrieved from Wrålsen et al. (2021)

2.3.1 End-of-first life for EV batteries

LIBs lose capacity during time and use due to internal chemical reactions that occur in the anode, cathode, and electrolyte. When an EV battery can no longer satisfy the standard use in EVs, it reaches its automotive EOL. The State of Health (SoH) parameter serves to determine the capacity available in a LIB. When available battery capacity declines to 70–80% of its nominal maximum capacity most battery manufacturers mark the end of the EV operation stage (X. Xu et al. 2021; Reinhardt et al. 2019; Zhu et al. 2021; Bobba, Mathieux, and Blengini 2019). Battery capacity normally remains at 80% after a car's warranty has expired, which is typically eight years given by manufacturers, while some studies claim that the actual lifespan of EV batteries is 12.5 years (Akram and Abdul-Kader 2021). Since technical advancement is extending the predicted life expectancy of LIBs, researchers predict that batteries will continue to operate properly inside the car for 15 years. Rapid technological improvements that characterize LIB development will affect how long future EVBs last (C. Xu et al. 2020).

2.4 Second-life of Electric Vehicle Batteries

The uptake of EVs results in an increasing number of retired batteries towards 2030 which indicates great potential for reuse of batteries. For batteries to have a lasting beneficial effect on the global energy transition, battery chemistries must consider the importance of implementing EOL strategies that facilitate reuse or recycling (IRENA 2017). Since EV batteries potentially hold a significant remaining energy capacity there is a possibility for second-life EV batteries to be applied in other applications (International Energy Agency 2022c). Additionally, research suggests that, rather than immediately recycling these EOL batteries following their initial use in an EV, giving degraded EV batteries a second life in less-demanding applications is technically and economically viable and preferable from an environmental standpoint (Ahuja, Dawson, and Lee 2020; Rallo et al. 2020; Reinhardt et al. 2019; Hill et al. 2019).

Repurposing is the process of modifying a product or some of its components for a different application than the product was originally designed for. It is interchangeable with second use or second life (Hill et al. 2019; Faessler 2021). The repurposing of EV batteries is a recognized strategy to minimize disposal and maximize the value of the batteries in a circular approach before recycling (Reinhardt et al. 2019; Albertsen et al. 2021). Typically, repurposing entails correcting any damage, reconfiguring the battery's cell structure, testing the cells' SoH, creating a new control system, and producing the necessary components (Foster et al. 2014). As a result, the second-life application may reduce the demand for the raw materials required to produce new batteries for the applications (Bobba, Mathieux, and Blengini 2019; Ahuja, Dawson, and Lee 2020; Tankou, Bieker, and Hall 2023).

2.4.1 Second-life applications

Retired EV batteries can serve in the market for BESS (International Energy Agency 2022c). The function of energy storage is the process of storing energy generated at one period for use at a later period to reduce imbalances between energy demand and production (Faessler 2021), the repurposing of an EV battery or its components in a BESS is considered to give it a second life. BESS aims to support the production of electricity from renewable energy sources like solar and wind energy, as well as ensure a consistent supply of electricity to support the electrification of the transportation industry and other energy-intensive sectors (IRENA 2017). Further, BESS is set to play an increasingly important role in system flexibility and is projected to be the fastest-growing source of power system flexibility (International Energy Agency 2022c; IRENA 2022). Consequently, repurposed EV batteries for BESS would foster the development of cleaner energy production and consumption in addition to increasing the longevity of battery life cycles before recycling (Hill et al. 2019; Faessler 2021; IRENA 2022).

Compared to first-use storage systems, stationary second use BESS are more cost-effective (Rallo et al. 2020), have a lower impact on the environment (Wrålsen and O'Born 2023), extend the lifespan of the second-life batteries, and slow the flow of batteries that needs to be recycled (Reinhardt et al. 2019). According to the literature, second-life stationary energy storage solutions for used EV batteries with previous EV service might provide up to 10 additional years of operation and are identified as one of the most prominent second-life strategies (Reinhardt et al. 2019; Bobba, Mathieux, and Blengini 2019). EV batteries can find a second life through vehicle-to-grid storage, reuse of batteries in large-scale, or home stationary energy storage as presented in Table 2-1. These solutions have the potential to lower material impact, save both energy and resources from further production or breakdown, and create opportunities for businesses (Thorne et al. 2021).

Table 2-1. Different BESS applications for repurposed EV batteries. Adapted from Hossain et al. (2019)

Application	**Services**	**Purposes**
Battery energy storage system	Mobile applications	EV charging stations
	Industrial and Commercial Energy Storage	Store electric power to supply during peak periods, balancing the load on the grid
	Residential Energy Storage	Generating, storing, and using electric power
	Grid Energy Storage	Connection to grids to facilitate reduction in peak load and stability in the power system

While the potential for repurposing EV batteries to BESS appears highly promising, there are still certain issues discussed in the literature that need to be addressed to facilitate the repurposing of EV batteries which will be presented in the following.

2.5 Barriers related to Repurposing EV batteries

A frequently mentioned barrier is related to the access to information from the BMS system, and further concerns related to extended producer responsibility are also mentioned in the literature which will be presented in the following.

Limited access to the battery management system

A limitation of second life batteries, along with a possible difficulty with repurposing procedures, is that EV batteries are designed for their first-use application, and consequently not technically ideal for second life use (Rallo et al. 2020; Reinhardt et al. 2019). Furthermore, the lack of data exchange from the BMS poses as a challenge related to repurposing EV batteries. To prevent hacking and secure business value, the BMS programming code and historical consumer data are protected by the OEM. This prevents external repurposing companies from obtaining a history of battery cycling and SoH, which is essential for understanding how spent batteries might be repurposed according to Faessler (2021). For instance, Zhu et al. (2021) observed difficulties for third-party repurposes in accurately assessing the salvage values from BMS as a frequent barrier from an economic and technical perspective, and that access to data related to battery performance evaluation is needed. Faessler (2021) and Hossain et al. (2019) also suggest this as a technical barrier. Similarly, Ahuja, Dawson, and Lee (2020), Hill et al. (2019), and Ahmadi et al. (2017) propose that the viability of repurposing is strongly dependent on the battery's SoH which currently is difficult to determine because of limited access to the BMS.

Developments are needed to secure necessary information related to assessing the SoH of EV batteries. Data availability and transparency across the battery value chain are critical needs for the industry to meet its growth and ESG goals. This will necessitate consistent, credible, and reliable data (McKinsey & Company 2023). According to Nurdiawati and Agrawal (2022), traceability allows retrieving the history of EV batteries, including the composition of EV battery's raw material – grade of product and its origin, which is important for allowing appropriate repurposing of EV batteries. The authors further suggests that new policies that encourage increased traceability can contribute to creating circular and commercially viable solutions for the repurposing of EV batteries (Nurdiawati and Agrawal 2022).

Global Batteries Alliance proposed the implementation of battery passports in 2019 (Global Battery Alliance 2023), which has been continued in the proposal for the European battery regulation from December 2020 (European Commission 2020b), which aims at promoting the CE along the entire battery life cycle in the EU. A battery passport, which allows information about the batteries to be transferred between parties, may essentially ensure that battery recovery organizations can classify the batteries based on their chemistry and use history. The implementation of the battery passport and interconnected data space will be critical for safe data exchange, enhancing battery market transparency, and the traceability of batteries throughout their life cycle (European Commission 2020a). According to the regulation proposal, each EVB shall have an electronic record i.e. battery passport by January 2026 (European Commission 2020b; Popp 2022).

Beginning in May 2023, the European Battery Regulation will be gradually introduced. The battery passport established a need for all storage systems to contain a visible QR code that provides extensive information about the battery such as composition, capacity, and durability. Batteries with higher capacity such as EV batteries must have a digital passport associated with them, comprising not only technical specifications but also environmental performance data, such as carbon footprint (European Commission 2020b). The battery passport will allow access to information on performance and durability parameters, and every battery must have a BMS to determine its state of charge and SoH from the battery's current values. The passport should improve economic operators' ability to make informed decisions in planning activities by allowing them to easily collect and use information and data about individual batteries in the market (European Commission 2020b).

Contradictions related to extended producer responsibility

Extended producer responsibility is defined as "*a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the entire life cycle of the product, and especially to take-back, recycling and final disposal of the product"* (Lindhqvist 2000 p. 154). Considering the new law on more sustainable and circular batteries in Europe, producers will be given more responsibility for their products (European Commission 2020b). By mid-2025, a more comprehensive regulatory framework on EPR will be in force, with greater collection targets gradually established (European Commission 2022).

In relation to the repurposing of EV batteries, several car manufacturers are currently employing solutions for the second life of used EV batteries prior to recycling. For instance, Renault is part of green energy projects where EV batteries are employed in stationary energy storage applications such as industrial applications (Schottey 2017). Similar projects are also featured by car manufacturers such as Volkswagen, Nissan, and BMW Group (Volkswagen Group 2023; Nissan Motor Corporation 2021; BMW Group 2022). What some of these companies have in common is that they have partnered with businesses that deal with the reuse or recycling of EV batteries. However, although EPR can lead to better life cycle management of products by increasing responsibility, it can appear as a barrier for individual repurposing companies because it might make OEMs reluctant to supply used EV batteries for repurposing (Hill et al. 2019).

To deal with the increasing volumes of EOL LIBs from EVs the repurposing of EV batteries is preferred, which necessitates the adoption of CBMs. Considering this, the next section of the literature review includes the introduction of circular economy, repurposing from a circular perspective, CBMs, and the barriers related to these models.

2.6 Circular Economy

The world's economy has been linear for a long time. In a linear economy, raw materials are extracted, processed into tangible goods, consumed by users, and then the product is disposed of as non-recyclable waste. This is the traditional industrial model of take-make-use-dispose. The environmental effects of this linear flow's production and consumption patterns have accumulated over time, and concerns about ongoing harmful effects drive our society to search for sustainable development solutions, such as a shift to a CE where take-make-recovery replaces take-make-dispose (Julianelli et al. 2020). The CE seeks to maintain the value of goods, components, resources, and materials for as long as possible in a closed-loop economy, and aims to tackle global challenges like climate change, biodiversity low, waste, and pollution (Ellen MacArthur Foundation 2015; Alamerew and Brissaud 2020). Companies that practice CE recapture resources at the end of their useful lives so they can be used repeatedly, in contrast to the conventional method of extracting materials from the ground, using them only once, and then disposing of them in landfills. For a system to be fully circular, waste must be completely phased out of the system, eliminating the need to extract new resources (Fraser, Haigh, and Soria 2023). Studies also indicate that 45% of the remaining greenhouse gas emissions that cannot be reduced only by transitioning to renewable energy sources can be reduced through the implementation of CE (Ellen MacArthur Foundation 2021).

2.6.1 Definition of Circular Economy

There is still no single definition of the CE, even though it has its foundations in various theories and frameworks and is a concept that both scholars and practitioners are very interested in. To address the stream of definitions and the unavoidable possibility of misunderstandings, Kirchherr, Reike and Hekkert (2017) analyzed 114 definitions of the CE and critically discussed their conceptualizations.

The authors suggested that the most renowned definition is put forward by the Ellen MacArthur Foundation (2013 p.7), which states that the CE is considered a "*Restorative and regenerative industrial system, by intention and design. It replaces the "end-of-life" concept with restorations, shifts towards the use of renewable energy, eliminated the use of toxic* *chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models".*

According to Kirchherr, Reike, and Hekkert (2017), several definitions have been created in accordance with the abovementioned definition, and in particular, definitions have been developed that include different circular economy-related activities such as repair, reuse, and recycling (Kirchherr, Reike, and Hekkert 2017). This can be seen in the definition developed by Geissdoerfer et al. (2017 p.759) which defines the circular economy as "*a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling".*

The latter definition of CE is used in this study because it presents both what circular economy is and indicates how a CE can be achieved. The definition also aligns with the four circular strategies emphasized in this thesis, which will be presented in the sections that follow.

2.6.2 Elements of the Circular Economy

Certain principles are recognized as core elements of the CE concept in the light of the Ellen MacArthur Foundation (Ellen MacArthur Foundation 2021). These include fundamental principles and strategies which will be explained further.

Principles of Circular Economy

In the literature, more principles have been emphasized over the years. For instance, the Ellen Macarthur Foundation (2021) and the Circularity Gap Report (2023) have both emphasized a set of principles and although being expressed differently, the principles refer to the same vision. The three principles of a CE, driven by design, are *to eliminate waste and pollution*, *keep products and materials in use*, and *regenerate natural systems* (Ellen MacArthur Foundation 2021). It is underpinned by a transition to renewable energy and materials. The first principle, *eliminate waste and pollution*, involves that products and services are designed to minimize waste and pollution at every stage of their life cycle (Ellen MacArthur Foundation 2023c, 2019). *Keep products and materials in use* is the second principle and emphasizes that products and materials are kept in use as long as possible through different strategies rather than being thrown away after use (Fraser, Haigh, and Soria 2023; Ellen MacArthur Foundation 2023b, 2019). The third principle, *regenerate natural systems*, supports the regeneration of nature by designing products and processes that minimize their impact on the environment and promote biodiversity (Fraser, Haigh, and Soria 2023; Ellen MacArthur Foundation 2023d).

The circular economy system diagram, also known as the butterfly diagram, can be interpreted as a visual representation of the three principles of the CE and illustrates the continuous flow of materials in a CE. The technical cycle and the biological cycle are the two main cycles as shown in Figure 2-5. In the technical cycle, processes such as reuse, repair, remanufacture, and recycling are conducted to keep products and materials in circulation. In the biological cycle, the regeneration of nature to natural systems is achieved by returning the nutrients from biodegradable materials (Ellen MacArthur Foundation 2023a).

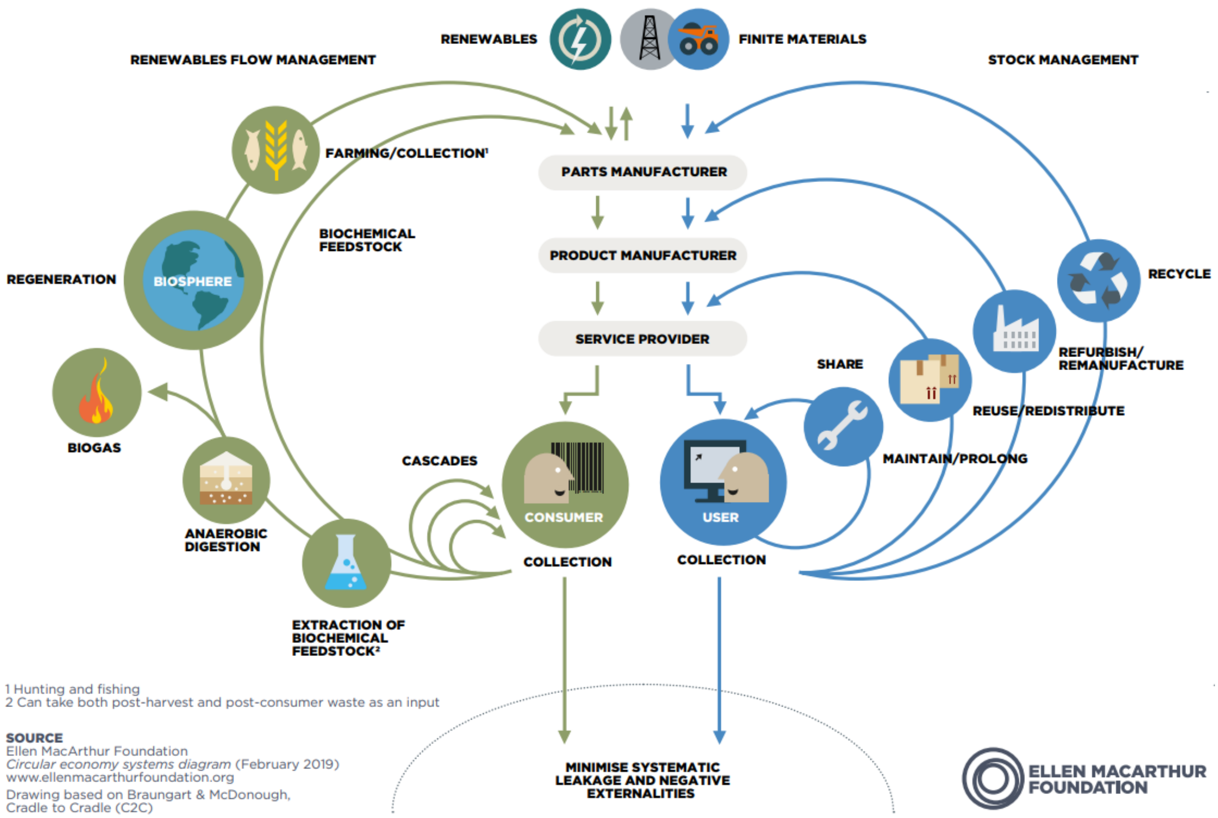

Figure 2-5. The Butterfly Diagram. Retrieved from Ellen Macarthur Foundation (2019)

The butterfly diagram visualizes how the *elimination of waste and pollution* can be achieved by using renewable energy, reducing material inputs, and minimizing the use of harmful chemicals. Further, the diagram illustrates that products should be repaired, reused, and recycled or composed within the two fundamental cycles which are in line with *keeping products and materials in use.* Additionally, the diagram indicates how this system can lead to the *regeneration of natural systems* by restoring ecosystems and protecting biodiversity (Ellen MacArthur Foundation 2023a). Overall, the butterfly diagram provides a helpful visualization of the three principles of the circular economy and demonstrates their interdependence and interconnection. A more resilient and sustainable economy that coexists with the environment can be created by bringing these ideas into practice.

2.6.3 Circular Economy Strategies

As stated, the aim of CE is to minimize material use, regenerate natural cycles, and prevent material losses. The key levers to transition towards a CE can be carried out by four main strategies as illustrated in Figure 2-6. The strategies are developed based on the work conducted by Bocken et al. (2016). The figure illustrates the four strategies which together constitute a closed-loop system. The four strategies will be presented in the following.

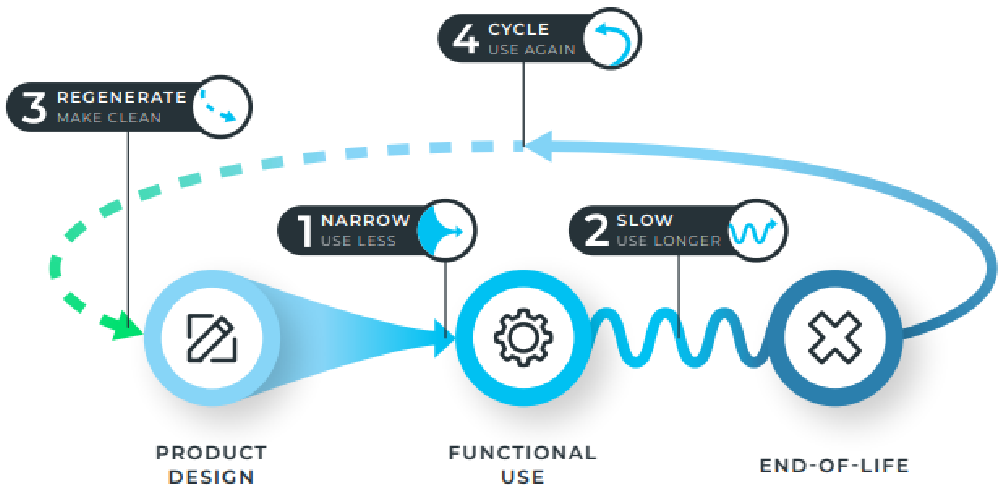

Figure 2-6. The four flows to achieve circular objectives. Retrieved from Fraser, Haigh, and Soria (2023)

Narrow: Use less

A fundamental principle of the circular economy is using less, the economy is embedded in nature, and nature has limits. Narrow strategies involve reducing the use of material and energy associated with the product and production process. Currently, material consumption is inefficient and unproductive, and businesses need to focus on using materials efficiently so that fossil fuels can be phased out (Fraser, Haigh, and Soria 2023; Bocken et al. 2016).

Slow: Use longer

Slow approaches, such as design for durability and repairability, seek to extend the useful life of materials. Because the materials, parts, and finished goods that are stored in inventories are long-lasting, a more circular economy is also a slower one. In the long term, this will reduce material demand, and effectively narrow the flow of resources (Fraser, Haigh, and Soria 2023; Bocken et al. 2016).

Regenerate: Make clean

By applying regenerative strategies, toxic or hazardous materials and processes are gradually phased out and replaced with regenerative biomass resources. In addition to attempting to replicate natural cycles, a CE seeks to maximize the amount of circular biomass that is used in the economy. Regeneration can happen both at the systems- and product levels (Fraser, Haigh, and Soria 2023).

Cycle: Use again

The goal of cycle strategies is to cycle and reuse materials at their best value. By maximizing the amount of recycled secondary materials, they ultimately reduce the demand for virgin material inputs and narrow flows. Naturally, certain virgin elements will always be required: To retain strength and functioning, some components must be blended with virgin materials because they all decay and can't be cycled indefinitely (Fraser, Haigh, and Soria 2023; Bocken et al. 2016).

2.6.4 A Circular Battery Economy

A circular battery value chain is recognized as an important contribution to achieving the Paris Agreement's 2°C target in the transportation and power sectors. As reusing batteries means extending their useful lives, i.e. slowing resource loops (Bocken et al. 2016), it makes a significant contribution to the CE by reducing the carbon investment made to produce the battery, and further delays the recycling of EV batteries (Albertsen et al. 2021; Ahuja, Dawson, and Lee 2020; Reinhardt et al. 2019). Further, repurposing favors the circular economy in terms of minimizing waste and extracting the value of the products, and is the preferred option compared to recycling (IRENA 2022; Hill et al. 2019). Avoiding the energy potential of used batteries will be an immense error, both economically and environmentally. The high labor and financial investments that were spent on these batteries will not be utilized to their fullest potential, and discarding the batteries to landfills will pose major environmental risks. Retiring these batteries after their first life becomes an economic waste, especially when a second life can add so much value to the economy (Hossain et al. 2019).

To ensure a company's success in repurposing EV batteries to BESS, it is important to develop and establish effective business models that facilitate repurposing. The following section will elaborate upon business models, CBMs, barriers related to CBM implementation, and how barriers can be addressed.

2.7 Business Models

A description of the business and a strategy for how it will make a profit is necessary for a company to move towards circularity. Business models (BM) define the way a firm does business and is key to illustrating the rationale of how an organization creates, delivers, and captures value for the business, customers, and wider group of stakeholders (Bocken et al. 2014).

2.7.1 Fundamental Business Models

Based on a wide range of literature, a widely accepted framework for BMs is presented by Richardson (2008), which states that a BM can be defined by three main elements; value proposition, value creation and delivery, and value capture mechanisms as illustrated in Figure 2-7 below.

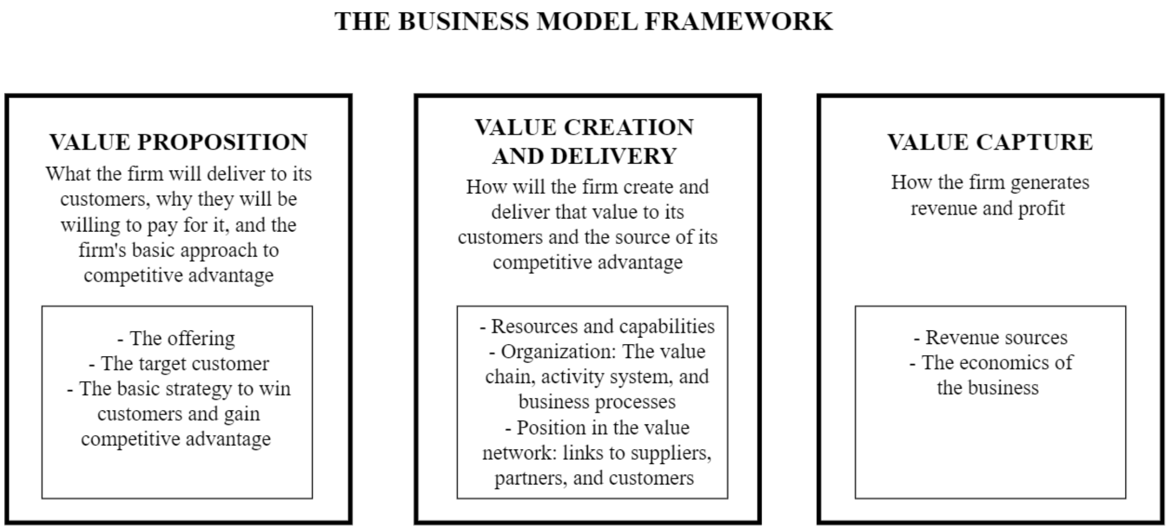

Figure 2-7. Business model framework. Adapted from Richardson (2008)

The value proposition often refers to the factors that make a customer value a company's product or service. Beyond what it will offer and whom it will serve, it is crucial to consider why the market is not being adequately supplied by other businesses. How, in other words, is the business going to improve? So, the value proposition can be seen as a presentation of the business's perspective on competition (Richardson 2008). *The value creation and delivery* outlines how the business will produce and offer its customers value. The sources of competitive advantages, i.e., resources and capabilities, as well as the processes involved in developing, producing, marketing, and delivering their offering to clients, are identified and explained. Lastly, *value capture* outlines the economics of the company, including the sources and streams of revenue, to show how the business is making money (Richardson 2008).

2.7.2 Circular Business Models

The concept of CBMs has evolved to support companies in operationalizing the CE in ways that deliver social, environmental, and economic value. CBMs are thought to be a crucial step for transitioning to a CE (Ellen MacArthur Foundation 2015). Business models for the circular economy are based on the principles of designing out waste and pollution, reusing products and materials, and regenerating natural systems, and is a plan for how a business can operate profitably while ensuring decreased environmental impacts through closed-loop supply chains and reduces resource consumption (Geissdoerfer et al. 2020). These models aim to reduce waste and maximize the value of resources by encouraging reuse, recycling, and remanufacturing (Bocken et al. 2016). According to Geissdoerfer et al. (2018), CBMs not only promote pro-active multi-stakeholder management and long-term perspective and create sustainable value but also narrow, slow, and close resource loops (Bocken et al. 2016).

A CBM is based on the business model principles of how a business provides, delivers, and captures value within closed material loops according to Bocken et al. (2016). There are different CEBM types, and they vary in how value is created (Lewandowski 2016). Companies can create value through exploiting the residual value from discarded products by extending life, recovering materials through recycling, or offering services rather than selling products (Lewandowski 2016; Bocken et al. 2016). Different criteria are used by scholars to classify CBMs (Lewandowski 2016), and they frequently depend on the extent to which resource loops are either slowed down or closed (Bocken et al. 2016). The business models regarded as P*roduct-as-a-Service (PSS)* and P*roduct Life Extension (PLE)* are business models that contribute to slowing down resource loops. Whereas R*esource Recovery* and C*ircular Supplies* are recognized as business models for closing resource loops according to Vermunt et al. (2019). Since the repurposing of EV LIBs can be regarded as slowing resource loops by extracting the residual value of the batteries this section will further elaborate on the business models of slowing resource loops.

Product-as-a-service

The transition from owning a product to providing its use or performance as a service is known as the product-as-a-service (PSS) model according to Vermunt et al. (2019). The value proposition within this CBM revolves around the delivery of the service to provide capability and functionality, while the ownership of a product remains with the company instead of the customer (Vermunt et al. 2019). The value creation and delivery is captured by the user which can focus on the use and access of the service as the inconvenience of the service or maintenance of the products is taken over by the manufacturer or retailer (Bocken et al. 2016).

Product Life Extension

Product life extension as a business model involves companies that aim to extend the life cycle of products, thereby creating value by exploiting the residual value of used products according to Bocken et al. (2016). Within this model, there is a distinction between the reuse strategies and the product upgrade strategies. Whereas reuse strategies entail the product being sold or used again right away, the upgrade strategy involve actions including repairing, refurbishing, or remanufacturing before the product is resold and reused (Vermunt et al. 2019). Repurposing is identified as a product upgrade before the product is resold or reused. These strategies improve product value without the product losing its function or identity (Bocken et al. 2016). Essential to the effectiveness of product life extension is the product design, which is influenced by the OEM of the product (Vermunt et al. 2019). Additionally, Bocken (2014) states that by utilizing this model economic value is captured by reducing costs through reusing materials, and environmental values are enhanced by reducing the environmental footprint and the use of virgin materials.

Similar to the abovementioned CBMs, Wrålsen et al. (2021) conducted research based on the CBMs proposed by Vermunt et al. (2019) and other researchers considering the repurposing of EV LIBs. The authors suggest that both the “product life extension by durable design, update services and remanufacture” and the “product-as-a-service" model were ranked as potential CBMs for repurposing practices. Where product life extension was highly ranked, a proposed CBM by the experts suggested a business model that combined remanufacturing, reuse, recycling, and waste management as the highest potential CBM for the specific case (Wrålsen et al. 2021).

Although there is high potential for CBMs in repurposing EV batteries, there are barriers that need to be considered in the implementations of CBMs, and how these can be addressed. The following section will present the barriers related to CBM implementation.

2.7.3 Barriers to Implementing CBMs

The literature typically categorizes barriers related to CBM implementation into external and internal barriers (Vermunt et al. 2019; Guldmann and Huulgaard 2020). Generally, the external barriers range from governmental barriers, supply chain and network collaboration, as well as uncertainty regarding a product’s residual value (Vermunt et al. 2019; Guldmann and Huulgaard 2020). The internal barriers are commonly regarded as a lack of managerial support, knowledge, resources, complexity in product design, and incentive structures (Guldmann and Huulgaard 2020; Vermunt et al. 2019).

Vermunt et al. (2019) claim that barriers continue to be overlooked in general and that there is a lack of conceptual clarity regarding how barriers may vary throughout the different CBMs. The author further stresses that failing to recognize the distinctions could result in incorrect generalizations about the barriers and contribute to a lack of understanding of the range of barriers for different CBMs. Furthermore, in a study about CBM implementation and barriers related to repurposed EV batteries, Wrålsen et al. (2021) suggest that barriers also can be case-specific and should be taken into account. Based on the suggested barriers from Vermunt et al. (2019) and studies related to barriers for EV batteries, the following section will describe the barriers related to the specific CBMs, namely PSS and PLE, and the perceived barriers to the case of repurposed EV batteries.

Perceived barriers to the Product-as-a-Service model

Organizational and financial barriers are the main barriers identified by companies with the PSS model (Vermunt et al. 2019). Legal challenges, such as contract and administrative barriers associated with leasing contracts, are related to organizational barriers. Businesses also identify difficulties in generating economic viability due to high service costs as financial barriers, in addition to the substantial up-front investments required. Furthermore, institutional and market barriers are identified as external barriers. When customers do not comprehend or accept the leasing agreements, market-related barriers emerge. Institutional barriers appear as a general lack of understanding of the CE in society and a lack of tested regulations. Likewise, investors are hesitant to invest in leasing agreements due to society's prevailing "buy-and-own" mindset (Vermunt et al. 2019).

Suggested barriers for the Product Life Extension model

Based on the findings from Vermunt et al. (2019) PLE models mainly encountered external market and supply chain barriers. Dependence on suppliers who do not prioritize reuse or third-party product design and information can lead to supply chain barriers since it creates conflicting interests in the SC. Further, market barriers are a result of consumer resistance caused by the low valuation of reusing products, indicating that the market demands "make-to-order" instead of standardization.

Barriers to the specific case of repurposed EV batteries

In the case of repurposing LIBs, Wrålsen et al. (2021) proposed nine barriers related to the implementation of CBMs of LIBs. The barriers, in descending order, were financial, technology, lack of technical standards, infrastructure, transportation cost of hazardous materials, market, legislation, human talent, and socio-cultural. It is relevant to mention that these barriers are proposed for the purpose of LIBs, and not directed at any specific CBM, indicating that potential barriers might vary for the given business models. However, it is valuable to include this research as it is case-specific.

The financial and technological barriers are identified as the main barriers related to LIBs (Wrålsen et al. 2021). The financial barriers considered issues related to financial viability and incentives, whereas the barriers related to technology were about the safety concerns around the LIBs (Wrålsen et al. 2021). Existing research has also acknowledged the profitability's uncertainty and indicates how it is sensitive to factors including the price of second-use LIBs, battery lifespan, discount rates, and efficiency (Rallo et al. 2020). Technical challenges were further suggested by Olsson et al. (2018) related to difficulties concerning the lack of standardization in design and uncertainty related to the state of the health of the batteries. This can also be related to the findings made by Albertsen et al. (2021) who state that access to the BMS system which would help assess whether a battery can be used in second-life applications including safety parameters makes a general difference. Furthermore, Albertsen et al. (2021) state that the volume of returned batteries was identified as a critical factor in the maturity of CE strategies for EOL LIBs, where there are potential challenges related to scalability because of the modest volumes of EOL LIBs today. This was also emphasized as a barrier by Olsson et al. (2018), who suggests that companies were not investing in the collection of existing batteries due to the low volumes.

Even though the abovementioned barriers are presented individually, Vermunt et al. (2019) and Wrålsen et al. (2021) stress that most barriers are interconnected, meaning that one barrier could be the result of another barrier, and identifying a dominant barrier is not expected. Although there is limited research on CBMs for EOL EV batteries, there are a few barriers identified concerning the implementation of CBMs. The next section will examine how these barriers might be overcome to facilitate a shift towards a more circular system.

2.7.4 Addressing the Barriers related to CBM Implementation

In addition to identifying the barriers to different CBMs, Vermunt et al. (2019) also investigated how companies were currently and could potentially overcome the barriers related to each model. Table 2-1 illustrates the main coping strategies suggested by the research conducted by Vermunt et al. (2019).

Table 2-2. Coping strategies to address barriers. Adapted from Vermunt et al. (2019)

Barriers to overcome	Coping strategies
Supply chain barriers:	
• High dependence on waste products and materials from other actors	• Building closer relationships with other actors in the supply chain to better influence product quality • Retaining product ownership to reduce dependence on third parties
• Lack of actors in the supply chain	• Stimulation current or new suppliers to develop circular materials and products through collaboration and co-investment
Market barriers:	
• Lack of awareness on the part of customers	• Building legitimacy and creating awareness
• Lack of knowledge and technology	• Experimenting with technology and developing knowledge • Searching for knowledge in new sectors • Outsourcing technical activities

Supply chain barriers

For the supply chain barriers, companies with the PLE model faced barriers because of their reliance on other supply chain actors. When businesses exploited waste products and materials from other companies, so-called "gap exploiters" (Bocken et al. 2016), dependence frequently occurred. Facing this barrier, actors in the supply chain should establish stronger relationships with each other. Secondly, collaboration with other companies in the supply chain could assure the quality of waste input (Vermunt et al. 2019).

Market barriers

For the market barriers, companies frequently encountered limited consumer and societal acceptance of trust in circular products. This was addressed by proactively raising awareness and establishing credibility in the market (Vermunt et al. 2019).

Knowledge and technological barriers

Vermunt et al. (2019) state that knowledge was sought in other sectors to develop their strategies and business models. Moreover, companies with the PSS model could outsource to law firms to form contracts for them or outsource their services to service providers. The researchers further state that the technological barriers were not prominent for their models because of the case companies investigated. Therefore, it is important to further investigate the potential for addressing the technological barriers to EV batteries. For the technical barriers related to EV LIBs, the need for standardization of diagnostics, health monitoring, packing, and labeling could simplify the process, but as common standards could interfere with competition between manufacturers this is a sensitive issue (Olsson et al. 2018). Furthermore, research indicates that battery disassembly is challenged by the large variety of EV battery designs currently on the market, implying that third-party reuse organizations are unable to plan ahead to optimize disassembly and determine the best second-life application (Zhu et al. 2021; Rallo et al. 2020).

2.8 Chapter Summary

The literature review presented has the aim to validate and justify the arguments employed in addressing this study's research problem. The literature relies on key components such as energy transition and repurposing EV batteries. Furthermore, the literature about EV batteries and CE is essential to understanding the general aspect of repurposing and the potential role of repurposing in CE. Additionally, the literature surrounding CBMs is essential to grasp how the company creates, captures, and delivers value and what barriers affect the implementation of CBMs. Based on the available data, the literature lacks aspects of CBMs in the case of repurposing EV batteries. Specifically, there are no evidence and documentation of how the barriers related to CBM implementation can be addressed in the case of repurposing EV batteries. The next chapter presents the research methodology employed by this study in answering the RQs.

3.0 Methodology

This chapter presents the methodological choices made for this study. To facilitate future replication, every decision of the research design should be explained. The "research onion"-model developed by Saunders, Lewis, and Thornhill (2019) is used to identify a suitable methodology for this thesis. The model demonstrates that the center of the onion is the procedures you use to collect your data for the research problem, and multiple layers must be removed to determine the data collection techniques and analysis procedures. When selecting the research methodology, these layers are regarded as core elements (Saunders, Lewis, and Thornhill 2019). All the layers presented in Figure 3-1 are included in this methodology followed by a discussion about the quality of this research. Initially, the methodology approach for this research can be regarded as a multimethod approach with a single case study and a literature review to answer the developed RQs.

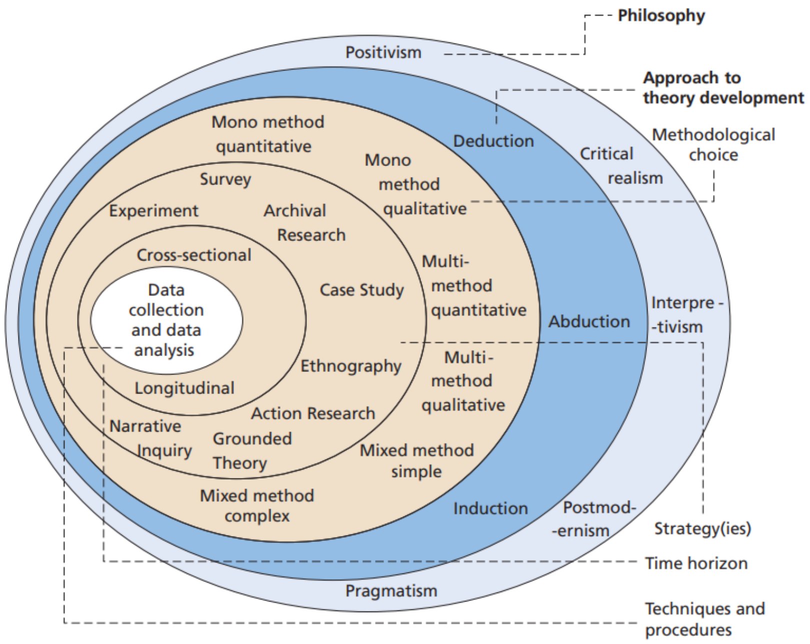

Figure 3-1. The "Research-onion". Retrieved from Saunders, Lewis, and Thornhill (2019)

3.1 Research Philosophy

The nature and development of knowledge are associated with a study's research philosophy. The selected research philosophy includes assumptions about the researcher's views of the development of knowledge of the world, which serves as the foundation for the research strategy. Saunders, Lewis, and Thornhill (2019) introduce epistemology, ontology, and axiology as three perspectives to consider in the research philosophy.

Epistemology is concerned with what the researcher perceives to be acceptable, valid, and legitimate knowledge in their topic of study which can be classified into three main perspectives namely, positivism, realism, and interpretivism (Saunders, Lewis, and Thornhill 2019). A researcher that adopts positivism as their research philosophy will typically work with subjects that can be observed. In this instance, a theory-based hypothesis will be developed, tested, and confirmed. Realism is likewise related to scientific exploration but varies from positivism because they believe that the external world exists independently of the human mind. Interpretivism is related to understanding a social phenomenon by interpreting the elements in the study. This is frequently employed when the subject of the research is humans as opposed to objects like computers or numbers (Saunders, Lewis, and Thornhill 2019). In this research, it can be argued that the literature study is based on realism because it seeks to explore the contributing role of repurposing in a bigger picture from an objective and fact-based perspective. Further, interpretivism is applied as the research philosophy in the field of epistemology. Through data collection and interpretation from the perspective of human actions and beliefs, the phenomenon of how CBMs can be implemented in the case company has been investigated. This can be argued by the fact that the data is gathered through interviews with informants who work at the case company, and their beliefs, experiences, and predictions are considered. Therefore, the RQs related to the case company are addressed by studying, interpreting, and comparing data from informants, and cannot be tested and verified using statistics and numbers (Saunders, Lewis, and Thornhill 2019).

Ontology is related to the assumptions made by researchers about human knowledge, and the nature of reality and the world. Ontology has two components: objectivism and subjectivism. Objectivism emphasizes structure and the existence of social entities independent of social actors. On the other hand, subjectivism argues that a phenomenon exists because of social actors' views and behaviors. It is based on the concept that to truly understand human actions, a researcher must investigate the subjective meanings of humans (Saunders, Lewis, and Thornhill 2019). It can be argued that this research is built on both subjectivism and objectivism. The literature review and corresponding RQ is based on an objective approach. Furthermore, the study is based on subjectivism because the views and opinions of humans are assessed to comprehend how the case company can implement a CBM, as well as the barriers they encounter and how they might overcome them. For example, difficulties are perceived to exist as a result of respondents' perceptions and cannot be properly understood and mitigated unless their subjective opinions are explored.

Axiology investigates in which way the researcher's values and ethics influence the research process. This is because the researcher's values may play a substantial effect in each stage of the research and must be considered for the credibility of the results (Saunders, Lewis, and Thornhill 2019). The philosophical approach used in a study reflects the researcher's values. For example, the preferred method of data collection in this study was interviews, implying that I value interaction with the participants more than anonymous data. Further, a literature study to answer one of the RQs can indicate that I value legitimate reports and data to create an image of repurposing from different perspectives. The choices made in this study demonstrate that I value human opinions and perceptions, as well as facts to answer the multiple RQs.

3.2 Research Approach

The research approach is concerned with how well the researcher understands the theory at the start of the research. Deductive, inductive, or abductive reasoning are the different research approaches (Saunders, Lewis, and Thornhill 2019). When a researcher makes a hypothesis and develops a research approach to test that hypothesis, it is referred to as deduction. Where the goal of the deduction is to test a theory, the goal of induction is to develop or build theory. In contrast to deduction, which employs a highly structured methodology, induction employs a less systematic method that may uncover alternative explanations of reality. While applying an inductive research approach, it is also recommended to use a small sample of informants, and qualitative data is mostly used. Finally, abduction starts with a surprising fact observation. This fact is a conclusion, and based on it, a collection of possible assumptions is developed and considered adequate or nearly adequate to explain the conclusion (Saunders, Lewis, and Thornhill 2019).

This study applied an inductive approach because its objective was to develop theory instead of testing it. Thus, this thesis employs a qualitative research method, contributing to an in-depth understanding of how repurposing of EV batteries can contribute to facilitating the energy transition, as well as the important aspects of CBM implementation. Because the purpose was to build theory, informants' beliefs and perceptions were considered to fully comprehend the phenomenon of how CBMs play a part in EV battery repurposing. Further, there was a need for specific data to answer the RQs and address gaps in the literature. The qualitative data has facilitated the documentation and understanding of the battery repurposing industry.

3.3 Research Design

The research design reflects the goals of the study (Yin 2018). It also specifies how the RQs will be answered, as well as how data will be collected and analyzed (Saunders, Lewis, and Thornhill 2019). In the literature, it is common to describe three different research designs: explanatory, descriptive, and exploratory (Yin 2018). Explanatory research seeks to establish causal linkages by testing hypotheses. Descriptive research seeks information to describe a phenomenon systematically, whilst exploratory research explores new knowledge and understanding of a topic and evaluates it in a new light (Saunders, Lewis, and Thornhill 2019). Creswell and Creswell (2018) state that the author of qualitative research will present a research problem that is best understood by exploring a concept or phenomenon and suggest that qualitative research is explanatory. Since this thesis allows for exploration to address the research problem, this thesis is recognized as exploratory. The exploratory research design for this study contributes to investigating the function of repurposing in the energy transition. Further, the exploratory stance made me able to understand how CBMs can be implemented, what associated barriers are perceived, and how these can be addressed.

3.4 Research Strategy

The multimethod approach has been applied to answer the RQs separately, meaning that this approach aims to answer the research problem with two different methods. Therefore, the first RQ is based on an integrative literature review to answer the question from a broader perspective with some insights from the interviews, and the three last RQs are based on the data collected from the interviews and secondary data from the literature.

When conducting an exploratory study, a case study approach is frequently used as it enables the researcher to obtain a rich understanding of the topic of the research (Creswell and

Creswell 2018). Yin (2018) differentiated between single and multiple case studies. When researchers want to investigate a critical or unique case, a single case study is typically chosen. This approach entails conducting an in-depth analysis of a specific case to obtain a deeper knowledge of the issue and to generate theories that can be tested in future research, whereas a multiple case study is used to determine whether a phenomenon exists in more cases (Yin 2018). This study used a single case study approach to understand the context of the research distinctively thereby studying the phenomenon in depth rather than in breadth. The objective of this study is to investigate the CBM implementation in the case company and discuss the associated barriers related to the implementation. This subject is still being researched in the literature, and more evidence is needed to build theory by confirming, challenging, or extending the theory (Yin 2018). The unit of analysis is the alternative circular business models, technologies, and practices for repurposing EV batteries. Additionally, an integrative literature review has been conducted to address the emerging topic of EV battery repurposing in the energy transition.

3.5 Time Horizon

When designing the research, the researcher must determine the most appropriate time horizon. The study can either describe a phenomenon that occurs over a specific period or capture a particular time (Saunders, Lewis, and Thornhill 2019). A cross-sectional or longitudinal study can be used to differentiate the time horizon. A cross-sectional study investigates a phenomenon at a certain period and is typically employed for time-constrained studies, whereas a longitudinal study investigates change and development over a given period (Saunders, Lewis, and Thornhill 2019). As this paper is centered on gaining knowledge of the subject over a limited time, it can be considered a cross-sectional study. Once the study's time horizon is determined, the final stage is to determine the method for data collection and analysis, which will be covered in the following section.

3.6 Case Description

This section will describe the selected case company in more detail. The case company is anonymous, and the sources used for the case description have been based on information from their website and the conducted interviews. For anonymity, the case company will from now on be referred to as Retecho with its real name.

Retecho is a tech start-up and energy company developing batteries for the future. The original idea of Retecho was based on the fact that there were so many electric cars on the market and that very soon there would be a sea of used batteries that had no place to go, and that the demand for batteries would be so huge that one would be forced to use electric car batteries again, and not just new batteries. The company aimed to create solutions for the repurposing of LIBs from the transportation industry to meet the ambitions of electrification and support the goals of decarbonization. However, due to decisive factors the company chose to direct its focus to developing new batteries for energy storage solutions based on a new technology with grade B lithium-ion cells, which are cells that do not meet the required standards of a LIB. With that being stated, the company currently has an ongoing project related to the classifications of cells for safe reuse from used EV batteries in collaboration with an established research institution in Norway. This project will be the basis for this thesis, with the aim to address how CBMs can be adopted, which barriers are related to the adoption of CBMs, and further how these barriers can be addressed.

The project related to the repurposing of EV batteries is based on a technology developed by Retecho that facilitates the reuse of battery cells by conducting individual cell control. This process involves putting a small cell on each cell to be able to connect the cells in and out of the serial string. This technology can contribute to driving each cell to its extreme and allows the cells to be based on using the good cells in a battery pack. With this technology, the lifetime of the cells can be run down to 40% residual capacity.

3.7 Data Collection

The research model needs to be developed to collect the necessary data and information to answer the RQs. An exploratory study typically collects data through a search of the literature, individual in-depth interviews, or focus group interviews (Saunders, Lewis, and Thornhill 2019). Data is categorized into primary and secondary data. Primary data is information gathered by researchers to answer a specific problem, e.g., what the researcher collects herself. Further, secondary data is already existing within areas where research is being done (Saunders, Lewis, and Thornhill 2019). To perform a high-quality case study, it is essential to use numerous sources of information rather than depending primarily on one. This allows a researcher to cover a wider range of historical and behavioral concerns (Yin 2018). To answer the RQs relevant information is needed, and employment of both primary and secondary data needs to be collected for this exploratory single case study. Ultimately, the information was analyzed to obtain relevant results. The assessment will be based on primary data collected through interviews with the case company, and secondary data collected through a literature study from a wide range of public sources, including reports, databases, and scientific papers.

3.7.1 Primary data collection

Interviews

Interviews are a systematic activity that is among the most frequent methods of data gathering with the goal of obtaining a certain type of information. Data collecting can take many forms, the most typical of which is person-to-person interactions. Interviews can be divided into multiple categories, often dependent on the level of structure. There are three main types: highly structured, semi-structured, and unstructured (Saunders, Lewis, and Thornhill 2019). Frequently standardized, predetermined questions are used in highly structured interviews, where an interview is conducted orally or in a written survey. Semi-structured interviews include a mix of organized and unstructured interview questions. The information required from all informants is often precise, and the questions asked are adaptable. Semi-structured interviews enable the researcher the ability to respond to the situation at hand. The third type is unstructured interviews, which are open-ended and exploratory in nature. This approach is more conversational and appropriate when the researcher is unfamiliar with the topic.

In this study, semi-structured interviews were used, with mainly structured interview questions. The data needed from the informants were specific, and the questions asked were adaptable. This type of interview enabled the researcher of this study to actively respond to the information provided by the informants. Because the research approach was flexible and inductive, and adjustments occurred as new data were acquired, this was advantageous for studying the topic. All the participants were interviewed this way, and the informants covered different departments of the company. Table 3-1 also includes a description of the interactions with the case company and informants.

The interviews were recorded with the participant’s consent. These recordings were later transcribed. The interviews ranged in length from 45 minutes to one hour. The disparity can be explained by how consistently they answered the questions and how much they deviated from the topic at hand. The interviews were conducted as verbal communication online and were carried out in real-time using computer-mediated communication technologies such as Teams. Online interactive interviews were also conducted via email. Because of the importance of the topic, a sample population was used in this study. In this study, the population was employees in Retecho, and three representatives were given as the sample. This number of employees was chosen because of limitations presented by the case company. It is a small organization, and while the preferred number was three to five informants the company was unable to provide this. Since the repurposing of EV batteries is an ongoing project established in collaboration with a research institute, there are a limited number of employees currently working on this project, resulting in a limited number of informants for this specific case. It is critical that the sample chosen is representative of the whole population, as this enhances the credibility of the study's findings. To establish credibility, the informants represent different positions within the organization, which allows to explore the RQs from various perspectives within the company. The informants were also selected based on their willingness to contribute to this study, and the case company aimed to find representatives who were relevant to the research. The next section presents the Retecho from a general view, as this company is anonymized for privacy reasons. Given the importance to secure the anonymity of the informants of the company, the results of the interviews are presented as Retecho, and not specific to any informant.

Table 3-1. Information about informants and interviews

Company	**Informants**	**Type**	**Duration**
Retecho	Informant one	Interview	1 hour.
	Informant two	Interview	45 min.
	Informant three	Email	-

The interview guide was developed using relevant literature and can be accessed in the appendix. To collect as much relevant data as possible, participants were sent an email before receiving the interview information letter. This action guaranteed that informants were prepared and could ask questions if they wanted. The interview guide included pre-written questions and themes. The interviews were conducted to discover how the organization implements CBMs and the related barriers in the case of repurposing EV batteries. The questions were designed to guide responses in the proper path by being both open and leading. The questions were also a mix of basic and topic-specific questions. Finally, the interview included defining specific terms, so when these topics were addressed, both the interviewer and the informant had the same point of reference.

3.7.2 Secondary data collection

In addition to the interviews, secondary data was collected through an integrative literature review. This can be reasoned based on a methodological perspective, as this was the best tool to answer the RQs, and especially related to RQ1. Before all research projects, relevant literature is essential (Saunders, Lewis, and Thornhill 2019). A literature review can address research problems effectively by integrating findings and viewpoints from many empirical studies (Snyder 2019). It can also provide an overview of topics where research is diverse and interdisciplinary. Furthermore, a literature review is an effective method of combining study findings to demonstrate evidence on a meta-level and to identify areas in which more research is required (Snyder 2019).

In this thesis, a literature review was performed to provide an understanding of the research problem and to develop a research strategy to answer the questions related to repurposing from a broader perspective. A literature review can be categorized as follows: systematic, semi-systematic, and integrative (Saunders, Lewis, and Thornhill 2019). A systematic literature review aims to synthesize and compare information through quantitative analysis. This produces specific RQs and evidence of impacts. Integrative literature reviews, on the other hand, aim to evaluate and synthesize using a qualitative method. The RQs are both narrow and broad, and the literature review is based on research articles, books, and other published texts. The contribution is typically a theoretical model or framework, as well as classifications. Between systematic and integrative reviews is the semi-systematic review (Snyder 2019).

Based on the qualitative approach, the literature review for this study pulls towards an integrative literature review. RQ1 is wide, and a knowledge foundation is necessary to analyze how the contributing role of repurposing from a broader perspective, and the purpose is to combine perspectives and insights from different fields (Torraco 2016). This topic is currently emerging, and the goal is to generate documentation for evidence.

The literature is collected from research papers, textbooks, and other published materials via Oria, which is the University College of Molde's database. This database provided access to several databases like ProQuest or ScienceDirect. Further, to conduct an extensive literature study, grey literature, including reports, policy literature or government documents, was also investigated to enhance the quality of the review to get a deeper understanding of how different concepts are addressed globally. To review the literature, it was essential to investigate repurposing from a wider perspective, resulting in a literature search for energy transition, energy storage systems, and electrification of transportation. Now that the data collection methods have been presented, an explanation of how the collected data was analyzed is provided.

3.7.3 Data Analysis

For the collected data to be relevant and understandable, the data must be analyzed. Qualitative data can take various forms, including written data such as emails and reports, as well as non-written data such as audio recordings. While conducting qualitative research with interviews, it is ideal to record the audio and then transcribe it into real quotes in a written document. In this study, data were acquired in both written and non-written forms, such as transcription and email. To guarantee that all data was included, all interviews were recorded with the participant’s approval. The audio recording secured accurate data and reduced control errors, as well as allowed the study's researchers to focus on the informant rather than writing notes. Following the interview, the audio was transcribed into a written document. The document contained all the records in written form and revealed when the informant spoke and when the researcher spoke. One limitation of the online interviews was that the audio sometimes cracked, which made it challenging to interpret what was said during the interview. This was adjusted by sending the transcriptions to the informants for corrections.

There are several existing analytical strategies. These strategies are classified as deductively based on analytical procedures and inductively based on analytical procedures (Yin 2018). Pattern matching or explanation building are examples of deductive strategies. Whereas the inductive approach for the analysis strategies includes data display and analysis, template analysis, grounded theory, analytical introduction, narrative analysis, and discourse analysis. In line with the methodology adopted in this study, the analysis process employed a strategy that encompassed data presentation and examination. The transcriptions were initially translated into English, with emphasis placed on identifying the key elements. Subsequently, the data was organized into tables to facilitate efficient handling and visualization. Validity and reliability are critical for ensuring valuable data and results from these methods which will be further presented in the following section.

3.8 Validity and Reliability

When conducting research, the credibility of study findings will always be a concern. Several elements influence this issue, including trends, instruments, and personal biases. The aim is to minimize the risk of getting incorrect results and thus make the research design important (Saunders, Lewis, and Thornhill 2019). Validity and reliability are two emphases of research design that aim to reduce the potential of incorrect replies as much as possible (Creswell and Creswell 2018).

3.8.1 Validity

Saunders, Lewis, and Thornhill (2019) state that the term validity refers to whether the findings of research deliberate to what they were meant to. Validity is classified into three types, namely construct, internal, and external validity (Yin 2018). Construct validity involves determining correct operational measurements for the researched concepts, for example, by including a variety of evidence sources such as documents, interviews, or observations. Internal validity, often referred to as credibility, addresses the topic of whether the research findings match reality. Collecting data from multiple informants is one approach for a qualitative researcher to establish internal validity. External validity addresses whether a study's findings may be generalized to different contexts or groups. The collected data for this study were based on specific concepts from the literature, and by using defined measurements for CBMs, it was straightforward to compare this to other similar concepts. Information from the literature review and interviews were also used as sources of information. The data in the interviews were gathered from multiple informants within the case company, ensuring a stronger probability of internal validity.

3.8.2 Reliability

The reliability of data collection and analysis refers to whether the results are consistent and if they would yield the same results if replicated by another researcher. Many risks to reliability exist, including errors and biases among both participants and researchers. As a result, it is essential that the research and data collection in this study to be published in a completely transparent manner, allowing others to evaluate the results for themselves and replicate the study (Saunders, Lewis, and Thornhill 2019). By including all documentation such as the interview guide (in the appendix), this study ensures transparency. Furthermore, the interview guides minimized leading questions and were divided into two sections: general questions and CBM-related questions. Because all interviews were done in Norwegian, the translation from Norwegian to English when presenting the results could contribute to reduced reliability.

In terms of the integrative literature review, all the sources are available and can be found online, meaning the study is highly reliable in terms of replication. It should be mentioned, however, that the use of other sources could result in different conclusions. With that stated this literature review has been carried out thoroughly and from a critical stance with the use of scientific references that have been thoroughly reviewed. However, because the development of technology or business models in this area is fast and review processes take a long time, I have had to use sources that have not been through such processes to some extent.

3.9 Chapter Summary

To demonstrate credibility, this chapter has provided important research methodology for this study. The research's philosophy and design, as well as data analysis and data collection methodologies, have all been addressed. Inspired by the research-onion model in Figure 3-1 above, Figure 3-2 below illustrates the choices that are made for the methodology in this thesis.

Figure 3-2. Methodological overview

Once the literature review and interviews were conducted, it enabled the research to present the findings from the data collection which is presented in the following chapter.

4.0 Results

This chapter will present the findings from the literature review for RQ1, and the analysis of the interviews. Based on the structure of the RQs, the first section will cover the RQs related to repurposing and energy transition. Further, the analysis from the interviews of Retecho is broadly categorized into the implementation of CBM, the perceived barriers, and how Retecho can overcome these barriers.

4.1 The Contributing Role of Repurposing to Facilitate the Energy Transition

The first RQ was developed to gain insight into how repurposing EV batteries can contribute to the energy transition and CE. To answer RQ1: "*To what extent could the repurposing of EV batteries for stationary energy storage systems facilitate the energy transition and contribute to the circular economy?"* this section aims to summarize the main findings from the literature review mainly based on the KPIs suggested from World Energy Transitions Outlook (IRENA 2022), and contributing aspects from the interviews conducted.

The findings from the literature review provide insight into the critical and pressing issue of decarbonizing society, emphasizing the necessity to reduce greenhouse gas emissions to mitigate climate change. The review further highlights that the energy transition is critical to achieving the objectives of net-zero emissions as outlined in the Paris Agreement (IRENA 2022; International Energy Agency 2022c; Fraser, Haigh, and Soria 2023; Jaramillo et al. 2022). This was also emphasized by one of the informants who stated that *"Why do we produce batteries and develop electric solutions? Truly it is only one rationale for this, and that is that we believe that one of the main forces to overcome CO_2 emissions, otherwise, investing in these technologies would not be necessary".* The findings indicate that the energy transition is essential for the decarbonization of society and that batteries and electrification of technologies are necessary to achieve the goal of zero emissions.

4.1.1 The potential for an increased share of renewable energy sources through BESS

The assessment of the literature emphasizes six essential KPIs for achieving the 1.5℃ scenario by 2050. The first KPI deals with the need for increased renewable energy to supply electricity generation (IRENA 2022), one informant emphasized renewable energy and the importance of storing this energy: *"With the ongoing restructuring that we have in the energy system if we are to be able to manage more solar power and wind power on the electricity grid which is much more variable. So, batteries are one of those things that force their way a bit, because we have to be able to store that energy when you have overproduction and be able to use it later."* The findings indicate that there is an increased demand for renewable energy and that there are challenges related to the variability and intermittency of renewable energy sources, which makes it essential to provide flexibility by storing renewable energy in BESS. This finding further suggests that batteries are the common technology for the storage of renewable energy and electrification of society, this has also been emphasized in the literature (IRENA 2022; Jaramillo et al. 2022; International Energy Agency 2022a).

4.1.2 Enhancing energy conservation through reuse strategies

To further facilitate the energy transition the third KPI aims to increase energy conservation and efficiency (IRENA 2022). According to the World Energy Transition Outlook (2022), this can be achieved by implementing CE strategies such as improvements in material efficiency and reuse. In relation to the repurposing of EV batteries, this was also emphasized by the informants on questions regarding CBM implementation and value creation, where one informant stated that "*First and foremost it is to keep battery cells in use for longer, as a lot of energy has first been spent on extracting raw materials and making these cells. So, one perspective is to keep products in use longer if you can."* The findings indicate that repurposing EV batteries can contribute to the CE by reducing the extraction of raw materials and using products for longer which further can result in increased energy conservation and efficiency.

4.1.3 Increasing electrification in the road transportation sector

The literature further emphasizes that electrifying technologies is a dominant aspect in the decarbonization of society, particularly in the transport sector as justified in the fourth KPI to reach net zero targets (IRENA 2022; International Energy Agency 2022c; Jaramillo et al. 2022; International Transport 2021; Fraser, Haigh, and Soria 2023). This is also emphasized in the interviews, where one informant stated that *"the economy of the future depends to a very large extent on being electrified and being part of the green shift"*. The findings suggest that the electrification of society is important to achieve the goals of net zero emissions by 2050.

The findings from the literature review and conducted interviews indicate that the repurposing of EV batteries can contribute to facilitating the energy transition by supporting the uptake of renewable energy and creating solutions to store energy, and by the implementation of circular strategies to facilitate energy conservation and efficiency. However, it will be essential to investigate how Retecho can implement CBMs for assessing the extent to which repurposing of EV batteries can contribute to facilitating the energy transition.

4.2 Circular Business Model and Strategy

This section aims to provide the findings to RQ2: *What are the solutions for managing the end-of-life of electric vehicle batteries in Retecho, and how do they apply to circular business models?* through the interviews conducted. As previously stated, Retecho is currently working on an EV battery repurposing project with a Norwegian research institute. Since this thesis is based on this project, the foundation for CBM implementation is specific to this project and not the company's other business areas.

4.2.1 Current practices for repurposing in Retecho

The traditional way of building a battery pack is to connect a lot of battery cells in series and put an inverter on the end to convert from direct current (DC) to alternating current (AC). Retecho has developed a new technology to facilitate repurposing and the use of battery cells, and the company stated that *"In Retecho, we put a small chip on each cell, so we can* *connect it in and out of the serial string. Then we drop that conversion at the end because it can make it in a way distributed between the cells as what we call switching technology. We are currently doing a pilot project with new cells to see if this works. This is a technology that will fit well with used electric car batteries*." This shows the company's current practices related to the repurposing of EV batteries, which are still under development. Further, the processes were described in more detail by one informant who stated that *"We call it individual cell control, so that the cells are no longer connected, but that they can be switched on and off as needed. Then we can drive each cell to its extreme, then we can use the good cells more and the bad cells less, so that on average they end up dying at about the same time. Then we maximize the lifetime of all cells and can run them all the way down to 40% residual capacity and get a long second life before they are recycled."*

4.2.2 The implementation of CBMs in Retecho

The interviews revealed that Retecho is familiar with the circular economy and has knowledge about how they promote the CE themselves. This appeared in one of the interviews where an informant stated that "*... Then there is the circular economy and reuse, so it is important that you get the smallest possible climate footprint on the systems you build, and then getting the longest possible lifespan of the battery cells is a very important part of that."* Furthermore, another informant stressed that it was too early to say how the company promotes CE because they don't have any production yet, only prototypes of their electronic developments. However, the informant further stated that "*What we can eventually contribute to is, of course, the reuse of used cells, and there is also provision for the use of all scrap from production, so we then extend the life of everything before it moves to recycling"*.

Finally, when asked about the value creation Retecho can make by developing solutions for repurposing EV batteries one informant stated that "*First and foremost it is to keep battery cells in use for longer, as a lot of energy has first been spent on extracting raw materials and making these cells. So, one perspective is to keep products in use longer if you can."* This indicates that the project related to the repurposing of EV batteries can be interpreted as a CBM because it can contribute to prolonging the life of used batteries, indicates that the informants have knowledge related to the ongoing energy transition, and what role repurposing of EV batteries can have in relation to a CE.

Although the responses from the interviews indicate that CBMs can be implemented for the project, there are some barriers emphasized by the informants that need to be identified. These barriers will be presented in the section that follows.

4.3 Barriers to the Adoption of Circular Business Models

This part provides the findings of RQ3: *"What are the barriers perceived at Retecho to the adoption of circular economy business models in the repurposing of electric vehicle batteries?".* The section begins with a presentation of what the informants of Retecho believe to be relevant factors, followed by a categorization of the findings in Table 4-3 according to the structure suggested by Vermunt et al. (2019). Initially, the findings will be summarized in relevance to RQ4.

The perceived barriers in the case company are categorized as internal and external. The barriers are related to finance, knowledge, technology, the supply chain, and the market. The subsections below will present the internal and external barriers.

4.3.1 Internal barriers

Financial viability barrier

When asked if there were any economic barriers related to the repurposing of EV batteries the informants' stated that the company has an ongoing project which receives support through an established program in Norway and that this facilitates the company to do the necessary research regarding repurposing. On the other side, it appears that there are some concerns related to the financial viability of repurposed batteries, especially for economies of scale.

When asked about the financial benefits of repurposing one informant stated that "*It is one of the things we need to find an answer to. You have to weigh the cost of the cell against how much it costs to test the quality of those cells afterward. Then you must weigh it up against the value of the raw materials that are in those cells to figure out whether you are better off sending it for recycling to build higher quality cells or whether you are going to use it longer".* Furthermore, when asked about how the project regarding repurposing can succeed, one informant stated that they need to address questions related to a financial aspect and claimed that *"The answer is purely technical: is it possible to develop processes to classify these cells in a way that is financially profitable?".* This indicates that there currently is uncertainty about the financial viability of repurposed EV batteries, and this qualifies as a barrier because it is a factor that the company needs to find a solution for.

Scalability barrier

The company stated that a challenge is related to the scalability of the process involving the repurposing of EV batteries. One informant explained that "*The first thing is that we are really trying to figure out how to test these battery cells in a way that is scalable. How do we find the errors that may be critical. It is important to solve this, especially in the situation when you get batteries that you don't know much about in advance".* This can be seen as an internal barrier related to technology and knowledge because it indicates that the company has yet not found solutions to reuse EV batteries in a way that provides scalability.

4.3.2 External barriers

Traceability barrier

An external factor related to technology is also classified as a barrier. When the company receives batteries, they have little to no information about the batteries in terms of raw materials, the quality of the cells, or the BMS. This was a factor that was frequently mentioned during one of the interviews, and the informant stated that "*Often you only have a snapshot, and you don't really know much about the history of how a car battery has been used. This is a purely technical challenge we are facing".* This indicates that there are external barriers related to the traceability of used EV batteries, making it challenging and time-consuming to determine the SoH of the batteries.

Extended producer responsibility barrier

In relation to the supply of used batteries, one of the informants emphasized the role of OEMs: *"... More car companies are starting to position themselves for second life. Volkswagen does it, BMW does it. There are many who have many mezzanines and large racks, and they know their own technology and the risks surrounding it. So, they are the best at creating systems and creating a circular economy put into a system. In addition to getting* *the packages back, they can repair a bit on the ones they have because they would like not to provide BMS data, they don't want to share what's inside. So, they have first-hand knowledge of their own."* Although the informant states that OEMs are the best at creating systems related to repurposing, this can be viewed as a potential supply chain barrier because OEMs are taking responsibility for retired EV batteries, which again limits access to batteries for independent third-party repurposes.

Market barriers

Concerning the availability of used EV batteries on the market one informant stated that *"It turns out that electric car batteries last longer than we expected. On average they last approximately 14 years. This means that the big wave of electric car batteries, i.e., from when electric cars with significant battery capacity began to arrive, was from 2014. If you add 14 years, we are in 2028. So, it will be quite far into the future that the first mountain of batteries from electric cars arrives in Norway."* This indicates that there currently is low availability of batteries on the market today, which initially is a restriction for the company to develop solutions in relation to repurposed EV batteries. This barrier is critical because of the company's ability to develop technologies related to repurposing depends on available batteries on the market.

As the findings indicate, there are several barriers related to the implementation of CBMs. The barriers discovered in Retecho related to the repurposing of EV batteries are illustrated in Table 4-3 below.

Table 4-1. Barriers to the implementation of CBM.

Barrier Categories	**Description**
INTERNAL	
Financial viability	Uncertainty regarding the financial viability of repurposing
Scalability	Lack of knowledge of solutions for scalability
EXTERNAL	
Traceability	Adverse technical standards for the traceability of EV batteries
Extended producer responsibility	Lack of actors in the supply chain
Market	Low availability of used batteries

As presented, there are internal and external barriers related to CBM implementation in Retecho. The internal barriers it is especially related to uncertainties about the repurposing of EV batteries, and the external barriers represent a lack of standards and availability in the market. The following section will present how Retecho can address these barriers from the informant's point of view.

4.4 Addressing the Barriers

To address the barriers presented in RQ3, the last research question was developed to gain insight into how the case company can overcome the barriers related to the project of repurposing EV batteries. To answer RQ4: "*How can these barriers be addressed to accelerate the transition towards a more circular system*?" the informants were asked how they could address the challenges they are currently facing in the project of repurposing of EV batteries. The discussion will follow the same structure as the section above, with the goal of addressing how to meet the barriers as outlined in RQ3. Initially, the suggested strategies for overcoming the barriers will be presented in Table 4-4.

4.4.1 Internal barriers

Financial viability barrier

There was a lack of suggested solutions from the informants related to the financial challenge of viability. However, as stated in the section above, this is the challenge the company is currently trying to overcome, to find financially viable solutions which can make repurposing scalable.

Scalability barrier

The barrier related to technology and knowledge regarding the scalability of repurposing EV batteries can be addressed by research and testing according to one of the informants: "*We have to make that process as research based as possible. So that we have to go through the whole process of going out wide and testing, and involving experts in relation to finding solutions that work".* By involving experts and testing their current technology can indicate that the company is continuously trying to find solutions that make these processes scalable, which in turn will contribute to figuring out whether their solutions are feasible concerning the financial aspect.

4.4.2 External barriers

Traceability barrier

The technical barriers were concerned with the lack of information and data related to the used EV batteries. In a question related to if there were processes in the whole battery value chain that could contribute to addressing the barriers it was stated that traceability could contribute to addressing current barriers, one informant informed that "*Traceability both on raw materials and data could address the technical barriers. When you receive packages that have the potential for reuse, that you have as much information as possible both on where the raw materials come from but also traceability on data. This concerns about how the qualities of the cells, can you get history from the batteries, can you have standards for reading out values from the control system so that those processes become easier".* In addition, the informant stated that *"It helps if you have some history and data from the use phase, and what the battery management systems say about the quality on these cells. I believe there is quite a lot of room for improvement for this process".* By enabling traceability, it indicates that it can benefit the company because it facilitates easier classification of batteries for reuse, which in turn can have an impact on the internal barriers faced by Retecho.

Extended producer responsibility barrier

There was a lack of suggested solutions from the informants related to the supply chain barriers concerned with OEMs increased responsibility. However, potential coping strategies will be presented in the discussion chapter in relation to existing research.

Market barrier

There was also a lack of suggested solutions from the informants related to the market barriers. However, from an overall perspective, the findings indicate that actors need to work together to achieve the goals of net zero.

Although there was a lack of suggestions on how to overcome the barriers related to the supply chain and the market, one informant stressed the importance of collaborations from a wider perspective. Specifically, the informant pointed out that to achieve net zero and decarbonize society, we are dependent on collaboration and working together. The informant stated that "*You have to have a world that plays together, that is a prerequisite to achieving net zero".* This can be interpreted as depending on several actors working together to achieve a common goal of decarbonization.

Table 4-4 below has been developed to illustrate what barriers the case company is currently facing, and strategies the informants suggested could be implemented to address these barriers.

Table 4-2. Coping strategies from the company's view

Barriers to overcome	**Coping Strategies**
INTERNAL	
Financial Viability	
Uncertainty regarding the financial viability of repurposing	
Scalability	
Lack of knowledge of solutions for scalability	Involving experts and testing current technology
EXTERNAL	
Traceability	
Adverse technical standards for the traceability of EV batteries	Enable traceability of the batteries to make it more accessible to determine the quality of the cells, the user-history, and what raw material is used in the batteries
Extended producer responsibility	
Lack of actors in the supply chain	
Market	
Low availability of used batteries on the market	

This section elaborated on how Retecho can overcome the identified barriers based on the informant's perspectives. The findings demonstrate that the internal barriers aimed at knowledge and technology can be addressed by involving experts and testing technologies, they also illustrate that the external barriers concerned with technology can be addressed by enabling traceability according to Retecho. Although there were some barriers without suggestions for strategies to overcome them, these will be further discussed in the chapter that follows to see how previous research can potentially contribute to the suggestion of strategies aimed at overcoming the identified barriers. The following chapter will elaborate on these findings in relation to the literature presented in chapter two with the aim to answer the four RQs for this thesis.

5.0 Discussion

The previous chapter presented the findings concerning the RQs used to investigate how repurposing of EV batteries can contribute to facilitating the energy transition, how CBMs are implemented in Retecho, as well as what the perceived barriers are and how they can be addressed. The findings will be used as a basis to compare and assess the topics to the theory established in the literature review, which was presented in chapter two. The first section will elaborate on the findings from the literature review and interviews to address the repurposing of EV batteries from a broader perspective to give insights into how they can contribute to the global energy transition. Further, the following section will elaborate on which CBMs are implemented in the ongoing project in Retecho, followed by a discussion of the barriers related to implementation. Additionally, a discussion of how these barriers can be mitigated to facilitate CBM implementation will be presented.

5.1 The Contributing Role of Repurposing of EVBs to Facilitate the Energy Transition

The findings from the literature review illustrate that the increase of renewable energy sources, energy conservation and efficiency, and the electrification of the transportation sector is among the top priorities for the ongoing energy transition to reach the 1.5℃ Scenario by 2050 (IRENA 2022). The literature further demonstrates that batteries are a key part of this transition, not only for the electrification, and thereby decarbonization of the transportation sector, but also for the storage of renewable energy sources which is fundamental to the growing renewable energy sector (IRENA 2022; International Energy Agency 2022c; Jaramillo et al. 2022). These priorities contribute to justifying why repurposing of EV batteries is important for the energy transition and the circular economy.

5.1.1 The potential for an increased share of renewable energy sources through BESS

The findings reveal how BESS can contribute to facilitating the energy transition though enabling the increase of renewable energy by developing energy storage systems. The literature research highlights the crucial need for a rise in renewable energy sources to supply electricity generation and mitigate the adverse effects of global warming (IRENA 2022;

International Energy Agency 2022c; Clarke et al. 2022). Achieving the KPI suggested by The World Energy Transition Outlook (IRENA 2022), related to the increased share of renewable energy necessitates a substantial boost in investments dedicated to advancing renewable energy technologies. As more renewable energy is deployed to enhance electricity generation and meet the 1.5℃ scenario, there is a greater demand for energy storage devices to provide flexibility and reliability of renewable energy sources. This further highlights the importance of developing and implementing energy storage technologies to successfully support the integration of renewable energy sources in the grid (International Energy Agency 2022c). This further corroborates with the findings from the interviews which suggested that the increasing share of renewable energy within the energy system inherently necessitates the demand for energy storage because of the variable nature of renewable energy generation and consumption. The findings also highlighted the relevance of batteries in facilitating energy storage systems.

5.1.2 Enhancing energy conservation through reuse strategies

The findings indicate that the reuse of spent EV batteries in BESS can result in energy conservation which implies that repurposing of EV batteries can contribute to facilitating the energy transition. The adoption of CE principles for EV batteries might underpin the energy transition by increasing energy conservation and efficiency as the third KPI in the World Energy Transitions Outlook 2002 emphasizes (IRENA 2022). As presented in the literature review, two of the principles of the CE are to eliminate waste and pollution, and to keep products and materials in use (Ellen MacArthur Foundation 2023c, 2023b, 2019). Implementing these concepts by facilitating the repurposing of EV batteries can ensure that important and limited resources are used longer, and circulated back in the economy, and will support the energy transition by increasing the potential to reach net zero emissions targets. As the CE encourages reduction, reuse, and recycling, major energy and GHG-intense virgin material processing can be avoided, resulting in significant carbon emission reductions (Bashmakov et al. 2022).

The findings from the interviews indicate that keeping the used EV batteries in use for longer will contribute to energy conservation in the form that repurposed EV batteries will reduce the demand for manufacturing new batteries for energy storage systems. This is also emphasized in the literature, where extending the useful life of EV batteries will contribute to meeting the growing demand for batteries for energy storage while expanding the usage of green energy. Not only does it promote the CE by applying slow strategies (Fraser, Haigh, and Soria 2023; Bocken et al. 2016), but essentially reduces the need to produce entirely new batteries for BESS and thereby leading to significant environmental and energy impact of raw material extraction and carbon emission related to manufacturing of the batteries and thus contribute to the transition to net zero. This is essential as there is an increasing uptake of EVs and thereby batteries that are manufactured and circulated in the economy (European Commission 2023b, 2023a).

5.1.3 Increasing electrification in the road transportation sector

The findings imply that the growing electrification in the transportation sector leads to a greater number of batteries in circulation, which eventually can be available for repurposing or recycling processes. The literature emphasizes that electrifying technologies is a dominant aspect in the decarbonization of society, particularly in the transport sector as justified in the fourth KPI which involves increasing electrification of end-users to reach net zero targets within 2050 (IRENA 2022). The findings from the interviews also underpin the literature by stating that the economy relies on electrification. Based on the increasing trend of EV fleet (European Commission 2023b, 2023a), and the continued target to electrify the road transportation industry (IRENA 2022; Fraser, Haigh, and Soria 2023; International Energy Agency 2022c; International Transport 2021), there will be several decommissioned batteries available for a second life in the coming years (International Energy Agency 2022c; Jaramillo et al. 2022). The life extension of these batteries can provide a cost-effective and long-lasting source for stationary BESS and can accelerate the shift from fossil fuels to renewable energy. From a broader standpoint, it is possible to infer that the increased electrification in the transportation sector, coupled with the growing share of renewable energy sources will result in an increased demand for energy storage. This consequently implies that a larger quantity of batteries will be in circulation, eventually becoming available for reuse and recycling processes.

As discussed, the findings suggest that the repurposing of EV batteries can contribute to facilitate the energy transition. This can be achieved by utilizing these batteries to enhance renewable energy sources through the development of BESS as well as promoting energy conservation by reusing EV batteries with the implementation of CE strategies. Lastly, the increasing electrification of the transportation industry can contribute to the future availability of batteries for second-life applications. Following the investigation of these important aspects, it becomes relevant to explore how Retecho develops solutions to repurpose EV batteries. The following section investigates the CBM that can be implemented related to the repurposing of EV batteries in Retecho.

5.2 The Adoption of Circular Business Models

The findings reveal how Retecho can create value by giving used EV batteries a second life by keeping products longer in the economy. The project related to the repurposing of EV batteries can be interpreted as a CBM related to the value creation of slowing resource loops (Bocken et al. 2016), where value is created through exploiting the residual value from discarded products by extending their life (Bocken et al. 2016; Lewandowski 2016). The findings further comply with the CBM *product life extension* which contributes to slowing down the resource loop by extending the life of EV batteries (Vermunt et al. 2019; Geissdoerfer et al. 2018). Similarly, Wrålsen et al. (2021) suggested that the business model "product life extension by durable design, update services and remanufacture" as an important CBM for EV battery repurposing in their research. Further, the repurposing of EV batteries can be viewed as an upgrade strategy where the batteries are being remanufactured before their new life in BESS without losing its identity (Vermunt et al. 2019; Bocken et al. 2016).

Business models for the circular economy are based on the principles of designing out waste and pollution, reusing products and materials, and regenerating natural systems (Bocken et al. 2016; Ellen MacArthur Foundation 2023a). This was also emphasized by Retecho, which believes that reusing EV batteries for BESS will lead to a reduction of emissions and higher resource utilization. This further contributes to the slowing and narrowing of resource loops (Bocken et al. 2016; Geissdoerfer et al. 2018), where the life cycle of batteries is slowed down by extending their lives, and indirectly narrows the resource loop by decreasing the demand for new materials. This can also be seen in the product life extension model for repurposing EV batteries, where used EV batteries are given a second life which essentially can reduce waste and pollution by reducing material demand, and effectively keeping the resources in the economy for longer. With this stated, there are barriers related to the utilization of CBMs which potentially hinders the company from creating and capturing value which will be discussed in the section that follows.

5.3 Barriers to the Adoption of Circular Business Models

The findings from this thesis identified several barriers related to the implementation of CBM for repurposing EV batteries. These barriers are discussed in more detail in the subsections that follow to answer RQ4: "*What are the barriers perceived at Retecho to the adoption of circular economy business models in the repurposing of electric vehicle batteries?".*

5.3.1 Internal barriers

Financial viability barrier

The financial consideration is a barrier mentioned by the informants. There is uncertainty regarding the financial viability of the process of repurposing, which the company is currently trying to find a solution to. For instance, the company explained that there is uncertainty regarding the current repurposing project about the financial viability. This can be interpreted as a crucial challenge because one of the main purposes of a CBM is to generate profit over time (Bocken et al. 2016). The uncertainty of financial viability further aligns with the findings from Wrålsen et al. (2021) who identified this as a highly ranked barrier concerning CBM implementation. Further, there are uncertainties related to quantifying the true economic value of repurposing batteries as it is still emerging, and the trend is for battery packs to be reused as a whole (Rallo et al. 2020; Hill et al. 2019). However, ignoring the energy potential of LIBs as waste would be a major mistake both economically and environmentally as a second life can increase the value of the use of the batteries (Hossain et al. 2019). As a result, the findings indicate that finding financially feasible solutions for repurposing EV batteries is critical for the success of CBMs.

The results from this study suggest that the company is currently trying to find solutions that make the repurposing processes financially viable. Since this project is supported by intensives to develop financially viable solutions, it indicates that for this specific case financial viability cannot be seen as a barrier since it is something the project is going to figure out. Therefore, the results suggest that the company does not perceive the financial viability as a barrier, but as a concern they are trying to find solutions to make the processes of repurposing financially viable. Additionally, research indicates that the condition and SoH of the battery heavily impact the feasibility of repurposing (Hill et al. 2019; Ahuja, Dawson, and Lee 2020; Zhu et al. 2021), indicating that several factors play a role in these processes meaning that barriers are connected. This will be addressed later in this chapter.

Scalability barrier

The findings imply that a barrier related to knowledge and technology evolves around the uncertainty around the scalability of repurposing EV batteries. The barrier related to scalability can be interpreted as Retecho does not currently have solutions that make repurposing scalable, which in turn affects the financial viability of repurposing. A similar challenge is suggested by previous research, whereas battery disassembly is made complicated by the wide range of EV battery designs currently in the market, this further implies that third-party reuse organizations cannot plan ahead to optimize disassembly methods to determine an ideal second-life application (Zhu et al. 2021; Rallo et al. 2020).

5.3.2 External barriers

Traceability barrier

In the literature, there are major concerns about the technical difficulties related to accessing the SoH of the batteries in repurposing EV batteries for a second life (Jaramillo et al. 2022; Zhu et al. 2021). Further, researchers suggest that EV batteries are designed for first-use applications, thus not technically optimal for second-life applications (Reinhardt et al. 2019; Rallo et al. 2020). Similarly, Retecho faces a barrier related to the traceability of EV batteries. This barrier is aimed at the lack of opportunity to obtain information about the battery's raw materials and previous use, which in turn leads to the company spending a lot of time - and thus money - to identify the batteries SoH. The findings correspond with previous research which discusses that the lack of data sharing from the BMS can make the repurposing of battery packs from EVs challenging (Wrålsen et al. 2021; Zhu et al. 2021). Furthermore, it was suggested that an external barrier can be related to the uncertainty about a product’s residual value with an unknown quality (Vermunt et al. 2019), indicating that this is perceived as a common barrier when implementing CBMs related to product life extension. Additionally, Ahuja, Dawson, and Lee (2020) suggested that the viability of repurposing is strongly dependent on the batteries SoH, indicating that these factors will determine whether the battery is suitable for repurposing or not and that these processes need to be traceable.

Extended producer responsibility barrier

The barrier related to potential supply limitations of batteries where OEMs are taking responsibility for managing their batteries at the end of first life can be viewed in relation to extended producer responsibility, where OEMs are obligated to take responsibility for EOL management of their EV batteries. More car manufacturers are also demonstrating that they are starting to position themselves for second life (Volkswagen Group 2023; BMW Group 2022; Nissan Motor Corporation 2021; Schottey 2017). Recognizing the increasing trend of OEMs taking responsibility for managing EV batteries at EOL can be interpreted because of the extended producer responsibility.

Further, one informant stated that OEMs are preferred to take responsibility for their EoL EV batteries because they have knowledge of the technology and related BMS system. This was also emphasized by Bocken et al. (2016) who stated that the ideal case for exploiting the residual value of a product is for manufacturers to develop business models that support reuse and remanufacturing themselves, instead of external companies independently doing so. Because OEMs will have access to the BMS and knowledge about the battery's technology, it will be easier for OEMs to determine the battery's SoH. Although extended producer responsibility can lead to enhanced life cycle management and thus facilitate the CE because OEMs are taking responsibility for their products throughout their life cycle (Bocken et al. 2016), it appears as a barrier for Retecho. This supply chain barrier limits the availability of collecting used EV batteries on the market. Extended producer responsibility was also emphasized as a barrier for individual repurposing companies according to Hill et al. (2019), because it might make OEMs reluctant to supply used batteries.

Market barrier

The findings imply that the expected lifespan of EV batteries is longer than anticipated, resulting in a lack of batteries on the market today. While most manufacturers have a battery warranty of batteries to last for eight years, recent studies claim that the expected lifespan of EV batteries is 15 years (Akram and Abdul-Kader 2021) and that the expected life will continue to increase due to technical improvements in the future (C. Xu et al. 2020).

Research conducted by Reinhardt et al. (2019) also suggested that the repurposed EV battery's market potential depends heavily on the market uptake of EVs and the future demand for storage solutions. Even though there is a growing trend of electric cars increasing in Europe and Norway (European Commission 2023b, 2023a), it will take several years before the EV batteries meet the end of their first life. From a circular perspective, this is advantageous because it initially extends the lifetime of EV batteries (Fraser, Haigh, and Soria 2023), however, it can indicate that batteries with a longer life span will hold a lower capacity after EOL as capacity fades over time and use and therefore affect the potential for repurposing practices.

5.4 Addressing the Barriers

Knowing which barriers Retecho is currently facing related to the adoption of CBM for repurposing EV batteries, this section is aimed at describing how the company can overcome the barriers to facilitate a more circular system (RQ5). This discussion follows the same structure as the previous section, intending to address how to overcome the barriers discussed in RQ4.

5.4.1 Addressing the Internal Barriers

Financial viability barrier

There was a lack of suggested approaches to overcoming the financial barriers related to repurposing EV batteries in Retecho as this is something the company currently is trying to find a solution to, which in turn is influenced based on their developed technologies for repurposing EV batteries. However, Zhu et al. (2021) and Ahuja, Dawson, and Lee (2020) indicated that there is a higher cost of the reuse processes because accessing the SoH is challenging for third-party companies, implying that other barriers related to scalability and disassembly should be addressed before evaluating the financial viability of repurposing. This suggests that Retecho should continue to develop its reuse procedures while simultaneously determining if these solutions are financially viable.

Scalability barrier

In relation to the scalability barrier of EV battery repurposing Retecho suggested that involving experts and continuously testing their current technologies can contribute to finding solutions that make these processes scalable. Likewise, Vermunt et al. (2019) suggested strategies such as experimenting with technology and developing knowledge for barriers related to the lack of knowledge and technology. This was also emphasized in the Norwegian battery strategy, which claimed that close collaborations between different centers of expertise, research institutions, the authorities, and the industry itself are important to develop battery solutions for the future (Norwegian Ministry of Trade 2022). By involving experts and testing their technologies Retecho can develop technologies to make the necessary testing related to EV battery repurposing scalable. In addition to developing solutions related to scalability, it has the potential to address the barrier related to financial viability. This requires Retecho to develop technologies that make the process of repurposing EV batteries scalable, which then can be evaluated in terms of financial viability.

5.4.2 Addressing the external barriers

Traceability barrier

The technical barriers were concerned with the lack of information and data related to the used EV batteries, which results in a time-consuming process of determining the battery's SoH. To overcome this barrier, Retecho suggested that traceability could facilitate the external technical barriers they are currently facing. By enabling traceability, the company would gain access to the raw materials used in the batteries, and data from the BMS to determine the quality of the cells and the history of how the batteries have been used. This was also emphasized by Nurdiawati and Agrawal (2022) who stated that traceability is important for allowing appropriate repurposing of EV batteries. The suggested approach to meet the technical barriers in Retecho can be seen in relation to the new battery legislation in the EU, where battery passports will be implemented to enable the traceability of used EV batteries. Battery passports aim at enabling the transfer of information about EV batteries between parties, effectively ensuring that battery recovery organizations can classify the batteries based on their chemistry and use history e.g., SoH. Further this implementation will enhance battery market transparency and the traceability of batteries throughout their life cycle (European Commission 2020a). Although this is a promising way to facilitate traceability for Retecho, the battery passport is still under testing and development, indicating that it may take time before it is implemented in practice. The regulation proposal also suggests that each battery should have a battery passport within January 2026 meaning that this technology still has some years before it will be seen in practice (European Commission 2020b).

As mentioned in the literature review, both Wrålsen et al. (2021) and Vermunt et al. (2019) suggested that barriers are connected, implying that addressing one barrier can contribute to meeting other barriers. In this case, it can be a link between the technical barrier and the internal barriers related to financial viability and the scalability of repurposing. The findings suggest that technical barrier related to traceability needs to be addressed to facilitate the repurposing of EV batteries. This was also emphasized by Ahuja, Dawson, and Lee (2020), Hill et al. (2019), and Ahmadi et al. (2017) who suggested that the viability of repurposing is depending on the batteries SoH, indicating that efficient processes are necessary to determine an EV batteries SoH to meet the requirements of repurposing. This can be demonstrated in Retecho, where addressing the barrier related to traceability could ease the internal barriers related to the uncertainty about financial viability and scalability of their current solutions related to repurposing.

Extended producer responsibility barrier

The barrier related to increased extended producer responsibility involves OEMs taking responsibility for used EV batteries, which initially hinders the company to collect used EV batteries. There were no suggested strategies to overcome this barrier according to the informants, but there are some apparent strategies for addressing this barrier in the literature. As the CBM regarded as product life extension generally encountered barriers related to the supply chain and dependence on suppliers, Vermunt et al. (2019) suggested that companies should enter into collaborations to facilitate the barriers related to the lack of actors in the supply chain. Further, Wrålsen et al. (2021) also proposed that cooperation among different stakeholders is necessary to facilitate CBMs.

The extended producer responsibility puts even more pressure on collaborations in the battery value chain. Facing this barrier, a suggested approach is for value chain actors to form collaborations to ensure the supply of used EV batteries. This is important because it can facilitate efficient EOL processes for OEMs, as well as meet the supply barriers for Retecho. Additionally, this could potentially facilitate technical barriers related to accessing the battery's SoH, because these collaborations with OEMs will both allow the supply of batteries, but also access to the BMS and related data, which could allow Retecho to easier determine the battery’s SoH. Therefore, is essential to emphasize that addressing the barriers related to accessing batteries in Retecho can have an impact on the barriers related to accessing the batteries SoH.

Market barrier

The market barrier is linked to the scarcity of batteries on the market today since the estimated lifespan of EV batteries is longer than originally anticipated. As this is an external barrier aimed at the market, where various factors will not be able to influence this barrier, it would not be well-reasoned to propose a strategy for Retecho to address this specific barrier. Nevertheless, it is worth highlighting that the market for EVs is expanding, not only globally but also in Norway. This suggests that more batteries will be available for reuse in the future. Additionally, recent reports indicate that electrification of the transportation industry is currently the most promising technology, not only for road transportation but also for emerging technologies in the maritime and aviation sector (International Energy Agency 2022c; IRENA 2022). This implies that the number of batteries on the market will increase in the upcoming years, which initially indicates that there will be an increasing number of batteries available for a second life in the future.

6.0 Conclusion

This chapter presents a summary of the research results, followed by a discussion of theoretical and practical implications. Finally, the limitations of the study and recommendations for future research are presented.

6.1 Summary of Results

The main purpose of this paper has been to investigate *"How does repurposing of electric vehicle batteries contribute to the decarbonization of society, and how can circular business models be implemented to facilitate repurposing?"*. The main conclusions and feasible solutions this research have contributed are presented in the following.

To address the research objective, this study aims at answering four RQs, where RQ1 is "*To what extent could the repurposing of EV batteries for stationary energy storage systems facilitate the energy transition and contribute to the circular economy?"*. The findings of RQ1 demonstrate that repurposing EV batteries to BESS can play an essential part in the energy transition as it contributes to storing renewable energy sources, which ultimately supports the net zero emission targets. Furthermore, it will initially limit the need to produce new batteries in the energy storage sector and thereby underpin the energy transition and CE by using less energy, facilitating solutions for energy storage, and slowing the resource loop by keeping EV batteries in use for longer.

In terms of the case study with Retecho about the implementation of CBMs, RQ2 is *"What are the solutions for managing the end-of-life of electric vehicle batteries in Retecho, and how do they apply to circular business models?"*. This RQ was addressed by asking the informants about the current processes related to the repurposing of EV batteries, and further how their practices may contribute to a circular economy. The informants described that the company has a project with a Norwegian research institute related to EV battery repurposing and that their technological solutions related to individual cell testing to repurpose EV batteries for BESS. Further, the informants emphasized that their solutions contribute to the circular economy by keeping batteries in the economy for longer, and thus that these processes contribute to exploiting the residual value of the used EV batteries.

The findings of RQ3, “*What are the barriers perceived at Retecho to the adoption of circular economy business models in repurposing of electric vehicle batteries?”*, imply that there are several barriers to the adoption of CBMs in Retecho. Multiple barriers were mentioned by the informants both from an internal and external perspective. This included barriers concerning finance, scalability, traceability, the supply of batteries, and the market.

Finally, RQ4 seeks to investigate “*How can these barriers be addressed to accelerate the transition towards a more circular system?*” to determine how Retecho can overcome the barriers outlined in RQ3. The informants suggested that enabling traceability, collaborations, involving experts, and testing their technologies would address some of the barriers faced in Retecho related to the repurposing of EV batteries and CBM implementation.

6.2 Implications

6.2.1 Theoretical implications

The objective of this analysis was to gain a comprehensive understanding of how repurposing could facilitate the ongoing energy transition, and how the case company can implement CBMs related to the repurposing of EV batteries. Additionally, the study aimed to disclose the barriers encountered in the implementation and propose potential strategies to overcome these barriers. In terms of theoretical implications, the originality of this investigation is that it has revealed how repurposing of EV batteries for BESS can have a significant impact on the energy transition, whereas previous research has overlooked this aspect.

Further, some studies have concentrated on CBM implementation and related barriers in the repurposing of EV batteries. In contrast, there is a lack of research investigating how individual repurposing companies currently developing solutions for repurposing EV batteries can implement CBMs. The thesis builds theory through the identification of CBMs related to repurposing, by discussing the factors influencing CBMs this thesis has increased the understanding of repurposing EV batteries in relation to CBMs. Furthermore, barriers to the implementation of CBMs have been identified and mainly corroborate with existing literature on the topic. However, the investigation emphasizes that there are crucial barriers that need to be addressed to facilitate CBMS related to the repurposing of EV batteries.

Finally, there is a lack of research surrounding how the barriers can be addressed to facilitate CBM implementation in the case of repurposing EV batteries. This was based on strategies suggested by informants but also provided by theoretical evidence.

6.2.2 Practical implications

While the managerial implications derived from this single case study may not be universally applicable across other organizations or industries, they still offer valuable insight and practical recommendations worth considering. It is important to recognize the context-specific nature of the study while applying the provided insights to inform decision-making processes.

Based on the literature study, this thesis suggests that repurposing of EV batteries is important for the ongoing energy transition and circular economy. Understanding the contributing role of repurposing EV batteries in the energy transition is important for encouraging more companies to develop solutions and for stabilizing the increasing global consumption of EV batteries. The findings of this study further illustrate that an independent repurposing company will face barriers related to the implementation of CBMs in repurposing EV batteries and that identifying barriers is critical to raising awareness about their complexities and how they may be interconnected across categories. This level of awareness can contribute to the successful implementation of CBMs. Additionally, strategies have been suggested to mitigate the barriers, which initially can contribute to valuable insight for the company and potentially other actors in the battery value chain.

6.3 Limitations of the Study

Some limitations have restricted the potential outcomes and affected the results throughout this research. These will be discussed in terms of how the limitations could have affected the outcome of this study. This study utilized a single case study approach which tends to focus on a specific phenomenon and thus limits the breadth of the research results. It may not provide a comprehensive understanding of the problem under investigation, and the results of this study might only apply to the case company and are not generalizable to other companies or industry practices. However, assessing one company employing a case study approach allows one to unravel the complexity of the industry, providing key insights that would not be discovered by different approaches. Moreover, the study has limited itself by investigating the repurposing of EV batteries in the Norwegian market.

Additionally, this study is based on a case company with a limited number of informants, where repurposing EV batteries is a project in the company and not their current focus. This in turn means that few people were working on the project, and getting everyone to contribute to this research was unrealistic. This has limited valuable information gathering. To get a better understanding of CBMs and related barriers, there can only be more insight to gain with a larger number of informants or more cases. By increasing the number of informants or multiple cases, additional contributing factors and barriers to repurposing could potentially be discovered or identified.

6.4 Suggestions for Further Research

The results and limitations of this thesis suggest some areas for further research to deepen the understanding of the function of repurposing EV batteries in the energy transition and CBM implementation. First, one of the suggested areas is to compare different companies utilizing repurposing of EV batteries for BESS, as this study only includes one company and their solutions. More companies in the battery value chain need to be explored to obtain knowledge of this growing industry and further the implementation of CBMs. Second, as this study only investigates a company in Norway, this should be extended to include more countries. It can be beneficial to providing internationally valuable research. Additionally, future research could involve other stakeholders to reveal different perspectives on repurposing EV batteries, particularly from the perspective of extended producer responsibility and the role of the original equipment manufacturer.

In conclusion, repurposing EV batteries to BESS is an area that requires further research from different viewpoints to investigate the role in the energy transition and further enhance the adoption of CBMs into the industry. Further research should continue to test and validate the findings in large-scale empirical studies, covering more companies and informants. To validate the results, corroborating studies are necessary to challenge and extend the results of this study.

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Appendices

Appendix 1: Interview Guide

Intervjuguide

Formålet med intervjuet

Bakgrunnen for denne forskningen er å undersøke gjenbruk av elektriske bilbatteri etter disse ikke lengre kan brukes til sin originale hensikt, samt hvordan denne prosessen kan rettes mot en sirkulær økonomi. Prosjektet tar utgangspunkt i ett selskap som bruker elbil-batteri til å utarbeide energilagringssystemer. Ved å undersøke nåværende prosesser og utfordringer vil oppgaven forsøke å knytte sirkulære prinsipper til bedriften, samt komme med forslag til hvordan de kan møte utfordringer i henhold til den sirkulære økonomien.

Definisjoner av begreper

- Med *Sirkulær økonomi* menes et regenerativt system hvor produkter skal være i økonomien lengst mulig ved å repareres, oppgraderes eller brukes igjen og til slutt brukes som råvarer i ny produksjon slik at minst mulig ressurser går tapt og utslipp reduseres.
- Med *batteriverdikjeden* menes hele prosessen fra utvinning av materialer, design, produksjon, transport, bruksfase, gjenbruk, og resirkulering av bilbatteriene.

Fremgangsmåte og anonymitet

Intervjuet vil bli tatt opp i et taleopptak og deretter transkribert. Utskriften vil bli sendt til det på e-post for bekreftelse og eventuelle rettelser. Lydopptaket vil bli slettet ved prosjektet slutt, 22. mai 2023. Transkripsjonen av intervjuet vil bli brukt i prosjektet og som vedlegg til masteroppgaven. Utskriften vil ikke inneholde respondentens eller selskapets navn, men bakgrunnsinformasjonen om respondenten og selskapet vil inngå i utskriften og bli aktivt brukt i masteroppgaven. Deltakelse i prosjektet er frivillig, slik at man når som helst kan trekke samtykket.

Generelle spørsmål

1. Fortell litt om bedriften og din rolle i selskapet
2. Hva går dine arbeidsoppgaver ut på?

Gjenbruk av bilbatteri

3. Hvilke faktorer har fått dere til å satse på gjenbruk av bilbatteri?
4. Kan du fortelle om prosessen rundt gjenbruk av elbil bilbatteri i Hagal?
    a. Hvor får dere tak i batteri?
    b. Hva slags bilbatteri er det? (kan dere ta imot flere typer? Har dere avtale med bedrifter?)
    c. Hvilke energikilder bruker dere for å produsere BESS?

d. Hva er estimert levetid for deres BESS?
e. Hva gjør dere med batterier som ikke kan brukes i energilagringssystem?

5. Hvilke faktorer bidrar til at dere lykkes med gjenbruk av batteriene?
6. Hvilken verdi skaper dere ved å gjenbruke elbil batteri?
7. Kan du si litt om ett/flere prosjekter hvor implementering av BESS har vært vellykket?
8. Samarbeider dere med noen bedrifter for å utvikle gjenbruk av elbil batteri?

Sirkulær økonomi

1. Hva slags erfaring har du rundt sirkulær økonomi?
    a. Hvordan jobber Hagal for å fremme den sirkulære økonomien?
2. Har Hagal iverksatt sirkulære strategier i sin verdikjede?
   Hvis ja:
    a. Hvorfor har dere valgt disse strategiene?
    b. Hvordan utnytter dere slike strategier?
3. Hva mener du i din rolle kan gjøre for å gjøre gjenbruk av batteri mer sirkulært?
4. Hva er de økonomiske fordelene med gjenbruk av batteri?
5. Hvordan bidrar gjenbruk av bilbatteri til det sosiale miljøet rundt oss?
6. Hva er de miljømessige fordelene med gjenbruk av bilbatteri?

Utfordringer

7. Hvilke utfordringer har dere identifisert når det kommer til gjenbruk av bilbatteri?
    a. Miljømessige utfordringer
    b. Sosiale utfordringer
    c. Økonomiske utfordringer
    d. Tilbud/etterspørsel av brukte bilbatteri
    e. Tilbud/etterspørsel av energilagringssystemer
8. Hvordan kan Hagal møte disse utfordringene?
9. Se for deg hele batteriverdikjeden for el-bil batteri: Er det andre prosesser i batteriverdikjeden som kan bidra til å møte disse utfordringene?
10. Er det noen reguleringer eller lover du mener bør bli endret for å kunne utvikle prosessene rundt gjenbruk av elbil batteri?

Annet

11. Er det noe du ønsker å tilføye?