TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

DRIVING CIRCULAR ECONOMY IN EUROPE: BUSINESS MODELS FOR SECOND USE OF LI-ION BATTERIES OF ELECTRIC VEHICLES

RINGMAJANDUSE EDENDAMINE EUROOPAS: ELEKTRISÕIDUKITE LIITIUM-IOONAKUDE TAASKASUTUSE ÄRIMUDELID

MASTER THESIS

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Department of Mechanical and Industrial Engineering

THESIS TASK

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DRIVING CIRCULAR ECONOMY IN EUROPE: BUSINESS MODELS FOR SECOND USE OF LI-ION BATTERIES OF ELECTRIC VEHICLES

RINGMAJANDUSE EDENDAMINE EUROOPAS: ELEKTRISÕIDUKITE LIITIUM-IOONAKUDE TAASKASUTUSE ÄRIMUDELID

Thesis main objectives:

1. Investigate existing EV battery second-use business models
2. Assess these models' practicality, focusing on their operational strengths and challenges.
3. Propose innovative improvements for sustainable, effective business models in the industry.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Literature Review	28.09.2023
2.	Data Collection	21.10.2023
3.	Data Analysis	27.12.2023

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PREFACE

This thesis, delving into the European electric vehicle (EV) battery recycling, repurposing, reusing, and remanufacturing industry, was initiated by my supervisors at Politecnico di Milano, Prof. Paolo Rosa, and Eng. Daniele Perossa. The significant research and analytical work of this thesis was conducted at both Politecnico di Milano and TalTech.

I am profoundly grateful to Professor Priit Põdra at TalTech for his invaluable guidance and expert consultation throughout this journey. His insights, expertise, and direction have been fundamental in shaping the trajectory and quality of this research. Additionally, I extend my sincere thanks to Prof. Paolo Rosa and Eng. Daniele for initiating this topic and providing critical support and resources essential for the completion of this thesis.

I also wish to express my gratitude to my family, friends, and peers for their continuous support and encouragement. Their unwavering belief in my abilities and constant inspiration have been a source of motivation throughout this academic endeavor.

This thesis provides a comprehensive exploration of the operational dynamics, challenges, and revenue streams within the EV battery recycling sector in Europe. It emphasizes the critical role of sustainable business practices, the necessity for collaborative efforts across the industry, and examines various revenue models shaping this vital sector. The findings of this study offer valuable insights for industry stakeholders, policymakers, and the academic community, contributing significantly to the evolving discourse on sustainable battery management in the European context.

Keywords: EV Battery; Recycling; Circular Economy; Business Models, Remanufacturing; Repurposing

1. INTRODUCTION

1.1 Background

The rise of electric vehicles (EVs) is a major step towards a more environmentally friendly way of getting around and is changing the car industry as we know it. At the heart of this change is the lithium-ion (Li-ion) battery. These batteries are essential to EVs and represent a strong commitment to a future that's better for the planet. Electric vehicles are more than just a new technology; they represent a shared effort to make transportation less harmful to the environment.

As countries around the world shift towards using electric vehicles, Li-ion batteries are becoming increasingly important. They are key to moving away from traditional, polluting energy sources. Governments are pushing hard to cut down on carbon emissions, and electric vehicles, which run on these batteries, are a big part of their plans to make the world more sustainable [1]

This study zeroes in on the fate of electric vehicle (EV) batteries in Europe when they reach the end of their first life. The emphasis is on the growing importance of reusing and recycling these batteries, a key factor in building a sustainable future. We're examining the strategies employed by European companies in managing these second-life batteries. Our research pulls together insights from a range of significant organizations and experts, spanning local European contexts. In doing so, we're contributing meaningful information to the ongoing discussion about the most effective ways to utilize and manage aging EV batteries, particularly in the European setting.

1.2 Free4Lib Integration

The research in this study is closely aligned with the objectives of the Free4Lib project, a European initiative dedicated to the efficient recovery of essential raw materials from lithium-ion batteries. Free4Lib emphasizes creating comprehensive recycling processes and technological solutions that are both sustainable and scalable. This involves innovative design for recycling new Li-ion batteries, developing a Battery Passport, and employing advanced recycling models.

The focus of this research contributes to the economic aspects of Free4Lib's mission, offering insights into the economic feasibility and potential models for the circular lifecycle of Li-ion batteries. By examining the practicalities of battery reuse, refurbishment, and recycling, this study enriches the Free4Lib project's broader goal of fostering a sustainable, circular ecosystem in Europe's Li-ion battery value chain. The resume of the project is shown in Appendix A.

1.3 EV European Market

The European electric vehicle (EV) market is witnessing a remarkable growth trajectory, reshaping the continent's automotive landscape and setting the stage for a more sustainable future. This transformation is fueled by a confluence of factors, including progressive policies, technological advancements, and evolving consumer attitudes [2].

1.3.1 Current State of the European EV Market

As of 2023, the European electric vehicle (EV) market continued to experience robust growth, with a notable increase in new EV registrations. This trend underscores a significant move away from traditional combustion engine vehicles. The European Commission's reports from early 2023 highlight this increase as a reflection of a broader shift in consumer preferences, influenced by heightened environmental consciousness and the improved affordability and availability of EVs. The market dynamics in 2023 demonstrate a sustained commitment to sustainable transportation solutions within Europe [3].

In 2022, Europe's electric vehicle (EV) market maintained steady growth, with sales exceeding 2.7 million, a 15% increase from 2021. This growth, though slower than in previous years, was significant amid a general decline in overall car sales. Europe accounted for a notable portion of global EV growth, with electric car sales constituting 21% of all European car sales. Germany led in volume, followed by the UK and France. Policy initiatives like the 'Fit for 55' package are expected to further boost sales, with stricter CO2 emission standards and incentives promoting low-emission vehicles. In early 2023, BEV sales increased substantially, indicating a continuing trend toward electric mobility in Europe expansion [4].

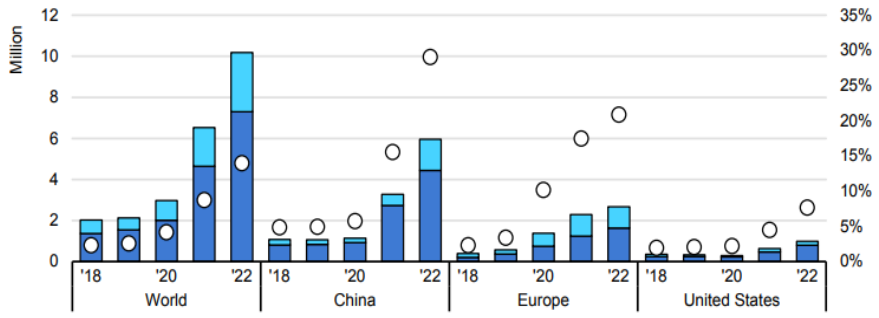

Figure 1.1 Electric car registrations and sales share in selected countries and regions, 2018-2022 Source: IEA analysis based on country submission, ACEA, EAFO, EV Volumes and Marlines [4]

1.3.2 Drivers of Growth

Several key factors contribute to the rapid expansion of the European EV market. Government Policies and Incentives: European governments have implemented a range of policies to encourage EV adoption. These include purchase subsidies, tax exemptions, and investments in charging infrastructure. The European Union's Green Deal and the Fit for 55 packages aim to reduce greenhouse gas emissions by at least 55% by 2030, positioning EVs as a crucial component in achieving these targets [5].

Significant strides in battery technology have enhanced the range and efficiency of EVs, addressing one of the major concerns of potential buyers. Research and development in battery technology continue to drive down costs and improve performance, making EVs increasingly competitive with traditional vehicles.

There is a growing preference for sustainable and environmentally friendly transportation options among European consumers. This shift is driven by a heightened awareness of climate change and its impacts, as well as the desire for innovative and technologically advanced vehicles.

Looking ahead, the European EV market is poised for further expansion. The International Energy Agency (2022) projects that by 2030, most new cars sold in Europe will be electric [6]. This forecast aligns with the European Union's broader environmental objectives and reflects the ongoing momentum in the EV sector.

The transition to electric mobility in Europe is also likely to be accelerated by the phasing out of internal combustion engine vehicles. Several European countries have announced plans to ban the sale of new petrol and diesel cars in the coming decades, which will inevitably boost EV adoption.

1.3.3 Challenges and Considerations

Despite the optimistic outlook, the transition to EVs in Europe faces several challenges. The development of a comprehensive and accessible charging infrastructure remains a critical issue. Additionally, concerns about the sourcing and recycling of battery materials, along with the need for a clean electricity grid to truly realize the environmental benefits of EVs, are areas that require ongoing attention and innovation.

1.4 Context and Broader Theme

In this study, we're closely examining how reusing and recycling EV batteries can contribute to a sustainable future, with a special focus on the economic aspects. We're not just theorizing; instead, we're diving into real-life business models to understand their financial feasibility and complexities. This practical approach helps us grasp the economic side of giving EV batteries a second life.

This research emphasizes the importance of economically sustainable practices in reusing and recycling EV batteries, which is key for a circular economy. As electric vehicles become more common, it's crucial to manage old batteries efficiently. This study, situated at the crossroads of sustainability and economic feasibility, aims to understand real-world business practices in battery lifecycle management. By incorporating insights from various sources, the study gains a broad perspective, aligning with global discussions on sustainable practices.

At the heart of this research is a strong commitment to significantly contribute to the ongoing conversation about the economic aspects of EV battery life cycle management. While environmental concerns are critical, the focus is on the economic sustainability of these practices, which is essential for a comprehensive and lasting solution.

The research involves a thorough examination of actual business models, analyzing their financial strengths, weaknesses, and overall performance. Through detailed examination of these models, the study seeks to derive practical insights that will aid in the development of economically sustainable practices in the evolving area of EV battery reuse and recycling.

In summary, the broader theme of this research is centered on the need to understand and improve the economic feasibility of reusing and recycling EV batteries. By investigating the second-life use of these batteries and examining real-world business models, the study aims to make a substantial impact on the economic landscape of sustainable battery management practices.

1.5 Overview of the Research Topic

At the intersection of the electric vehicle (EV) revolution and sustainable technology, this research embarks on a comprehensive journey, moving from the expansive landscape of EV advancements to the specialized realm of the second-life use of batteries. The introduction serves as a navigational guide, steering readers through the broader contexts that contextualize the significance of EVs and gradually focusing on the nuanced domain of battery reuse.

As the narrative progresses, the focus seamlessly narrows down to the intricate domain of the second life use of batteries. This transition is not abrupt but deliberate, guiding

readers through the contextual nuances that define the importance of extending the life cycle of batteries beyond their initial application in EVs. The narrative strategy is intentional, allowing both experts and those unfamiliar with the subject matter to traverse the evolving landscape with ease.

Crucial to this journey is the clarification of definitions that form the foundation of the research. In recognizing the diverse audience that engages with this discourse, the introduction takes deliberate strides to elucidate terms and concepts fundamental to understanding the intricacies of battery reuse. This commitment to clarity ensures that the research remains accessible and insightful, catering to a spectrum of readers ranging from industry professionals to scholars and enthusiasts.

In essence, the overview of the research topic serves as a dynamic preamble, setting the stage for a nuanced exploration into the second life use of batteries. From the sweeping panoramas of the EV revolution to the specialized domain of battery reuse, this introduction is a deliberate and thoughtful guide, inviting readers to delve into the multifaceted dimensions of a sustainable and evolving technological landscape.

1.6 Contribution to Research

At the heart of this research endeavor lies the overarching goal to contribute substantively to the body of knowledge surrounding the industrial-scale business models in the second-life use of electric vehicle (EV) batteries. This contribution is propelled by a clear recognition of existing gaps and limitations within the current landscape of research, signaling the need for a nuanced understanding of the intricacies involved in repurposing and recycling EV batteries.

One of the primary objectives of this research is to serve as a bridge between theoretical frameworks and real-world industrial practices. While theoretical constructs provide a conceptual foundation, the pragmatic realities of business models in the second life use of EV batteries demand a more applied and empirical approach. By immersing itself in the operational realities of companies actively engaged in battery repurposing and recycling, this research endeavors to move beyond theoretical abstractions and offer insights grounded in practical experience.

The significance of industrial-scale business models cannot be overstated, especially in an industry as dynamic and evolving as the second life use of EV batteries. Through meticulous analysis, this research aims to showcase the importance of these models and their role in shaping the trajectory of sustainable battery practices. It seeks to unravel the intricacies, challenges, and potential improvements within these models, providing a comprehensive understanding that extends beyond the theoretical realm.

By substantiating the importance of these business models, this research aims to enhance the current body of knowledge, offering valuable insights to researchers, policymakers, industry practitioners, and other stakeholders. It aligns itself with the broader discourse on sustainability and the circular economy, contributing not only to academic inquiry but also to the practical considerations of businesses operating in this domain.

In essence, the contribution to research is twofold: firstly, by addressing gaps and limitations in existing studies, and secondly, by elevating the discourse around industrial-scale business models in the second life use of EV batteries. This research aspires to be a catalyst for informed decision-making, innovation, and sustainable practices in an industry that plays a pivotal role in shaping the future of clean and efficient energy solutions.

1.7 Research Objective

This research is guided by three overarching research objectives that serve as the compass for the subsequent investigation into the business models governing the second life use of electric vehicle (EV) batteries. These objectives are strategically formulated to steer the study's direction and focus, ensuring a comprehensive and insightful exploration of this dynamic and evolving domain.

Objective 1: Unraveling Existing Business Models, the first objective is to unravel the intricacies of the existing business models employed in the second life use of EV batteries. This involves a meticulous examination of diverse approaches and strategies adopted by companies engaged in repurposing and recycling EV batteries. By conducting a qualitative inquiry into these models, the research aims to uncover the underlying mechanisms, strengths, and potential areas for improvement within the current landscape.

Objective 2: Assessing Effectiveness and Challenges Building on the understanding gained from the first objective, the second objective focuses on assessing the effectiveness of these business models. This involves a qualitative inquiry into the operational dynamics, success factors, and challenges faced by companies in the practical implementation of their second life use strategies. By identifying both strengths and weaknesses, this objective aims to provide a nuanced evaluation that goes beyond theoretical considerations.

Objective 3: Proposing Improvements and Innovations The third and final objective is to leverage the insights gained from the previous objectives to propose improvements and innovations within the realm of second-life use business models. This forward-looking objective aims to contribute to the continuous evolution of sustainable practices

in industry. By identifying areas where innovation is needed and suggesting practical improvements, the research seeks to guide companies toward more effective and environmentally friendly approaches.

These research objectives are interconnected and mutually reinforcing, creating a holistic framework for the investigation. They reflect a commitment to not only understanding the current state of business models but also to contribute actionable insights that can drive positive change in the second life use of EV batteries. Through a qualitative inquiry that delves deep into industry practices, this research aims to provide a roadmap for businesses, policymakers, and researchers navigating the complex terrain of sustainable battery practices.

1.8 Personal Motivation

My personal motivation for researching the recycling and repurposing of EV Li-ion batteries stems from a deep-seated interest in the economic aspects of emerging technologies, reinforced by over five years of experience in battery pack manufacturing. This experience, particularly in producing battery packs for electric vehicles, has given me a profound understanding of the complexities in battery development and the need to focus on the economic implications of battery end-of-life.

Driven by the rapid growth of the electric vehicle industry and the increase in battery production, I recognized the importance of exploring the economic factors in the recycling and repurposing phases. This interest is part of a larger commitment to addressing real-world economic challenges, bridging the gap between theoretical knowledge and practical solutions.

Recycling and repurposing are key elements of the circular economy and pivotal in my research, reflecting my dedication to sustainable economic practices. This project not only fuels my current research but also aligns with my long-term vision for a sustainable economic future, aiming to integrate my manufacturing experience into economically viable strategies for EV Li-ion battery recycling and repurposing.

The next chapter will outline the research methodology, discussing the blend of qualitative and quantitative methods used for data collection and analysis. It will detail the rationale behind these methods, the data gathering process, including the questionnaire approach, and the use of statistical tools for analysis. Additionally, the chapter will address the research's ethical considerations and challenges, providing a thorough background for the study's findings.

2. METHODOLOGY DESIGN

In this chapter, the methodology adopted for our research is presented. This chapter outlines our comprehensive approach, detailing each step of the research process. It starts with an explanation of our research design, elaborating on the rationale behind choosing specific methodologies and how they align with the research objectives. Then the data collection methods are described, providing insights into how and why particular data was gathered. This is followed by a detailed account of how the study participants were selected, ensuring a representative and relevant sample.

Next, we delve into our data analysis techniques, highlighting the tools and statistical methods used to interpret our data. The whole process is shown in Fig 2.1. This section is critical for understanding how we arrived at our conclusions. Ethical considerations, a cornerstone of our research integrity, are discussed to demonstrate our commitment to responsible research practices. Finally, we acknowledge the limitations of our study, reflecting on the challenges we faced and how they impacted our research.

This chapter is not just a procedural description but a narrative of our journey through the research process. It is integral to comprehending the validity and reliability of our results and serves as a roadmap for those who wish to assess or replicate this study. By detailing this methodology, we provide transparency and rigor, ensuring that our research contributes meaningfully and ethically to the field of study.

Figure 2.1 Thesis Work Flow

2.1 Research Design

Our research adopted a mixed-methods approach, combining quantitative and qualitative analysis, to provide a comprehensive understanding of the recycling and remanufacturing practices in the European EV battery industry. This approach was chosen for its ability to yield both numeric data, allowing for statistical analysis, and rich, detailed qualitative insights, which are crucial in understanding the complexities and nuances of business practices in this sector.

2.1.1 Why Mixed-Methods?

Mixed-methods research is particularly effective when exploring new or complex phenomena, as it allows for a more holistic view [7]. In our case, quantitative data helped in identifying trends and general patterns in the industry, while qualitative data provided deeper insights into the practices, challenges, and experiences of the companies involved in the recycling or remanufacturing of EV batteries.
The quantitative research component of our study primarily involved the evaluation and interpretation of the data. This approach was particularly suited for assessing business practices, business models [8], and their effectiveness in the European context. We focused on analyzing responses to understand patterns, preferences, and perceptions within the industry. By categorizing and examining qualitative feedback, our analysis aimed to quantify trends and commonalities in business approaches and attitudes towards battery recycling and reuse, providing insightful metrics for understanding the current state of the European EV battery recycling market.

2.2 Data Collection

Data collection was primarily conducted through LinkedIn, utilizing the platform's vast network to identify relevant companies and employees. A targeted keyword search was employed, focusing on "recycling and remanufacturing" within the European context. This approach ensured that the data was relevant and specific to the research area.

2.2.1 Identifying Companies

The research spanned across Europe, focusing on a range of industries associated with the second-life use of EV batteries. This encompassed not only recycling entities but also organizations involved in manufacturing, refurbishing, repurposing, and disposal of batteries. The aim was to create a detailed picture of the varied business models and practices prevalent in the European market, especially concerning the lifecycle and after-use strategies of EV batteries

2.2.2 Reaching Out to Employees

Once relevant companies were identified, a search was conducted for employees who were likely to have insights into the company's practices. This included individuals in

managerial positions, those working in supply chain departments, or employees directly involved in the operations.
Employees were contacted via LinkedIn messages, where we explained the purpose of our study and invited them to participate in the questionnaire. This approach allowed us to directly reach individuals with relevant knowledge and experience, ensuring the validity and relevance of our data.

2.3 The Questionnaire

The questionnaire, developed following the literature review presented in Chapter 3, was tailored to gather specific data about the current operations and business models in the second-life use of EV batteries across various European industries. While it consisted of structured questions designed for quantitative analysis, these questions were crafted to cover key areas such as insights into the strengths, challenges, and strategies employed in the industry. This was achieved by offering a range of response options that could capture the nuances of respondents' experiences and views on recycling, refurbishing, and repurposing EV batteries. The complete questionnaire is included in Appendix B for reference.

Question 1: What is the main business of your company?
The initial question of the questionnaire was designed to determine the primary business focus of companies participating in the study, pivotal for understanding the diverse landscape of the European electric vehicle (EV) battery sector.
This question provided options like Recycling and Remanufacturing/Repurposing, along with an open-ended 'Other' category for companies to specify different business activities or sub-activities. The inclusion of these options was crucial to categorize companies according to their core operations within the EV battery lifecycle, a fundamental aspect for contextualizing subsequent analysis.
This classification was essential to frame the study's further exploration into the specific challenges, technological innovations, and business models prevalent in each segment.

Question 2: What could be the main strengths of your business model?
This question aimed to uncover the perceived strengths within business models in the EV battery recycling and remanufacturing sector, offering a range of strategic advantages for analysis.
Efficient and Cost-effective Recycling Processes: Focused on evaluating operational efficiency, crucial for market competitiveness.

Advanced Technology and Equipment for Battery Analysis and Testing: Aimed to gauge companies' technological capabilities in delivering quality and innovative solutions.
Strong Partnerships with Key Industry Stakeholders: Assessed the impact of collaborations with EV and battery manufacturers on resource sharing and market expansion.
High-quality Standards for Products: Highlighted companies' commitment to quality, influencing customer trust and reputation.
Diverse Sales Channels and Distribution Networks: Investigated market reach and penetration effectiveness.
Robust Research and Development Capabilities: Explored the role of R&D in driving innovation and long-term industry sustainability.
Established Customer Base and Brand Reputation: Assessed market presence and brand strength.
Commitment to Sustainability and Circular Economy Principles: Evaluated alignment with environmental sustainability practices.
Access to Funding or Government Support: Looked at how external financial and policy support aids operations.
The objective was to pinpoint areas where companies excel, offering insights into their business strengths and the elements contributing to the effectiveness, profitability, and sustainability of their models in the industry.

Question 3: What could be the main weaknesses of your business model?

This question sought to identify weaknesses in EV Li-ion battery recycling, remanufacturing, repurposing, and reusing business models, focusing on operational and strategic challenges.
Lack of Access to a Consistent Supply of Used Batteries: Examined sourcing challenges critical for recycling operation sustainability.
High Costs of Recycling/Remanufacturing Processes: Explored financial barriers impacting business viability.
Limited Tech for Efficient Battery Analysis/Testing: Emphasized the role of technology in process effectiveness.
Insufficient Partnerships with Industry Stakeholders: Assessed how collaborative networks influence business success.
Inconsistent Quality Standards: Investigated quality control issues vital for customer trust and compliance.
Regulatory and Environmental Compliance Challenges: Focused on difficulties in adhering to legal and environmental standards.

Limited R&D Capabilities: Highlighted the importance of innovation for competitive advantage.
Limited Brand Recognition/Customer Awareness: Tackled market presence and consumer education challenges.
Lack of Funding/Government Support: Looked at financial and policy constraints affecting recycling initiatives.
The aim was to understand the hurdles faced by businesses in the EV Li-ion second-life sector, crucial for strategizing improvements and enhancing overall business model effectiveness and sustainability.

Question 4: To what extent has your company formed partnerships with other industries (e.g., automotive, energy, electronics) to improve your business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing?

This question aimed to evaluate cross-industry collaborations' impact on business models in the EV Li-ion battery recycling, repurposing, reusing, and remanufacturing sector. The options ranged from extensive partnerships to limited or no collaborations, assessing their influence on business improvement.
Established Extensive Partnerships: Identified companies with wide-ranging, cross-industry collaborations key for resource sharing and market growth.
Formed Some Partnerships with Room for More: Recognized companies initiating collaborations, with potential for deeper alliances.
Limited Partnerships with Minimal Impact: Explored the extent and effect of restricted partnerships on business models.
Not Actively Pursued Partnerships: Catered to companies with independent approaches or those not engaging in cross-industry collaborations.
Uncertainty or Lack of Knowledge: Allowed respondents unsure about their company's partnership strategies to express this.
The goal was to understand the role of inter-industry partnerships in business model enhancement, their contribution to technological and operational advancements, and market competitiveness. It also aimed to identify potential areas for increased collaboration, guiding strategies for future growth and sustainable practices in the EV battery lifecycle management.

Question 5: What challenges does your company face in its current business model for recycling, repurposing, reusing, and remanufacturing EV Li-ion batteries?

This question aimed to pinpoint challenges in the EV Li-ion battery recycling, repurposing, reusing, and remanufacturing sector, covering operational, technological, financial, and market-related issues.

Lack of Consistent and Reliable Supply of Battery Packs: Addressed supply issues crucial for continuous operations.

High Costs Associated with Recycling, Repurposing, Reusing, and Remanufacturing Processes: Focused on financial barriers impacting cost-effectiveness and profitability.

Limited Technological Capabilities for Efficient and Effective Battery Pack Handling: Examined challenges in technology, affecting operational efficiency and effectiveness.

Difficulties in Meeting Quality Standards and Ensuring Safety and Performance: Explored issues in maintaining quality and safety, essential for trust and compliance.

Lack of Awareness and Demand for Recycled or Repurposed Battery Packs: Addressed market challenges in building awareness and demand for recycled products.

Regulatory and Compliance Challenges: Investigated difficulties with environmental and waste management regulations.

Limited Access to Funding or Investment: Identified financial challenges in expanding and improving operations.

Lack of Skilled Workforce: Focused on the challenges of having a skilled workforce in this specialized sector.

Competition from Other Companies: Examined how competition affects business strategies and operations.

The purpose was to explore the diverse challenges faced by companies, offering insights for improving and adapting business models for growth and sustainability in the EV Li-ion second-life sector.

Question 6: Do battery pack manufacturers take recyclability and repurposability into consideration when designing battery packs?"

This question was crucial for assessing battery pack manufacturers' commitment to environmental foresight and sustainability. It aimed to determine the extent to which recyclability and repurposability are prioritized during the design phase of battery packs, essential for fostering a circular economy in the EV industry.

Regular Consideration of Recyclability and Repurposability: Targeted manufacturers who consistently factor in recyclability and repurposability in their design processes, indicating a proactive stance toward environmental sustainability and resource management.

Intermittent Consideration: Addressed manufacturers who occasionally incorporate these aspects into their designs, recognizing the importance but not yet fully integrating it into all design processes.

Rare Consideration: Identified manufacturers who infrequently consider recyclability and repurposability, underscoring an area for improvement and the need to heighten awareness about the benefits of environmentally conscious design.

7. What specific regulations or policies does your company follow to maintain an economically sustainable business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing?

This question examined the regulations and policies followed by companies in the EV Li-ion batteries sector to maintain economically sustainable and responsible business models for recycling, repurposing, reusing, and remanufacturing activities. The responses provided insight into the strategic approaches for regulatory compliance and economic viability:

Stricter Regulations on EV Li-ion Battery Disposal: Assessed whether companies align with or advocate for tighter disposal regulations, which can enhance recycling effectiveness and reduce environmental impact.

Financial Incentives or Subsidies: Investigated reliance on economic support from governmental bodies, critical for balancing the costs of recycling and remanufacturing processes.

Standardized Guidelines and Lifecycle Handling Procedures: Explored adherence to guidelines for safe, efficient handling of EV batteries throughout their lifecycle, ensuring operational consistency and safety.

Promoting R&D in Battery Recycling Technologies: Identified companies involved in or supporting R&D to improve recycling efficiency, reduce costs, and lessen environmental impact.

Extended Producer Responsibility (EPR) Programs: Indicated participation in EPR programs, where manufacturers manage the recycling of their battery packs, fostering end-of-life product responsibility.

The question aimed to uncover how companies adhere to regulatory and policy frameworks to ensure their practices are both environmentally sustainable and economically viable, navigating the complexities of compliance and economic pressures in EV battery lifecycle management.

8. What strategies does your company employ to incorporate principles of the circular economy in its operations

This question delved into how companies in the EV Li-ion battery recycling, repurposing, reusing, and remanufacturing industry apply circular economy principles to enhance both environmental and economic sustainability. The responses provided insights into the various strategies embraced by these companies.

Efficient Resource Management and Waste Reduction: Assessed companies' efforts in optimizing resource use and minimizing waste.
Promoting Repair, Refurbishment, and Reuse: Examined how companies focus on extending product lifecycles through repair and refurbishment.
Facilitating Product Take-back and Recycling Programs: Investigated involvement in programs for recycling or repurposing end-of-life products.
Collaborating with Suppliers for Sustainable Sourcing: Looked at partnerships aimed at sustainable material sourcing.
Exploring Innovative Business Models: Assessed adoption of new models like leasing or sharing to promote sustainability.
Educating Consumers on Circular Economy Benefits: Explored efforts to inform consumers about sustainability and circular economy principles.
Implementing Reverse Logistics for Returns and Recovery: Examined logistics for product returns for recycling or repurposing.
The study aimed to uncover how companies in the EV Li-ion battery sector integrate circular economy principles into their operations, a crucial aspect for the field's sustainable development.

9. In your business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing, how do you distribute your value proposition to different customer segments?

This question investigates the distribution strategies of companies in the EV Li-ion battery recycling, repurposing, reusing, and remanufacturing sector, essential for understanding their approach to reaching and serving varied customer segments. The responses cover a spectrum of distribution methods, each reflecting a different aspect of market engagement and strategic approach:
Direct Sales to EV Manufacturers and Supply Chain Companies: Examines direct B2B relationships, evaluating how companies cater to other businesses in the supply chain.
Partnerships with Retail or Distribution Channels for End-Users: Explores B2C strategies, assessing how companies access individual consumers through established retail or distribution networks.
Collaborations with Specialized Service Providers or Intermediaries: Investigates the role of partnerships in expanding market access, especially in specialized services or niche areas.
Customized Strategies Based on Customer Segment Needs: Assesses adaptability in distribution models to cater to specific customer needs, reflecting customer-centricity.
Combination of Multiple Distribution Channels: Looks at the use of mixed distribution strategies, indicating a comprehensive approach to market reach and risk management.

This analysis is key in understanding companies' strategic positioning in the market, revealing how they tailor their approaches to meet the diverse needs of different customer segments.

10. Are there any emerging technologies or innovations that you think could significantly improve the efficiency or effectiveness of your company's business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing?

This question aimed to identify emerging technologies and innovations influencing business models in the EV Li-ion battery recycling, repurposing, reusing, and remanufacturing sector. The options ranged from advanced sorting technologies to AI applications, each representing potential breakthroughs in battery lifecycle management:

Advanced Battery Sorting and Separation Technologies: Explored the use of innovative methods for efficient component sorting and separation.

Automated Disassembly and Recycling Systems: Assessed the implementation of automation in disassembly, enhancing process efficiency and safety.

Enhanced Battery Testing and Evaluation Techniques: Investigated advancements in testing for battery health and functionality, key for reusing and repurposing batteries.

Advanced Battery Diagnostics and Refurbishment Tools: Focused on new tools for battery diagnostics and refurbishment.

Novel Recycling Methods: Looked at innovative recycling methods, including hydrometallurgical and pyrometallurgical techniques.

Battery-to-Battery Recycling Processes: Examined direct recycling approaches preserving original battery materials.

Energy Storage Systems Using Recycled Battery Packs: Considered using recycled batteries in energy storage systems.

AI and ML for Process Optimization: Explored AI and ML applications in optimizing recycling processes.

Blockchain for Supply Chain Traceability and Transparency: Assessed blockchain technology's role in enhancing supply chain management.

These options provided insights into potential technology drivers shaping the future of the EV Li-ion battery sector.

11.What value propositions differentiate your company from others in the EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing industry?

This question explores the unique value propositions that set companies apart in the EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing industry:

Cutting-edge Proprietary Technologies or Innovative Processes: Assesses whether companies have developed unique technologies or processes that enhance efficiency, effectiveness, or cost-effectiveness, distinguishing them in the market.

Expertise and Experience in the Industry: Evaluates the depth of knowledge and experience companies have, which can be crucial in understanding and meeting the specific requirements for successful battery pack recycling and remanufacturing.

Broad Network of Strategic Partnerships: Looks at the extent of a company's network within the EV industry, including collaborations with automakers, battery manufacturers, and other related companies, which can provide valuable resources and opportunities.

Proven Track Record and Successful Case Studies: Considers the company's history of successful projects, demonstrating their ability to deliver high-quality, reliable, and cost-effective solutions.

Competitive Pricing and Cost Structures: Examines if the company offers financially attractive solutions for customers seeking cost-effective and environmentally responsible options for used battery packs.

This question and its choices aim to identify the key factors that differentiate companies in this competitive sector, offering insights into their competitive advantages and market positioning.

12. What are the main sources of revenue for your business model in the EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing industry? How does your company generate income from its activities?

This question assesses the main revenue sources for companies in the EV Li-ion battery recycling, repurposing, reusing, and remanufacturing industry:

Fee-based Revenue from Recycling or Remanufacturing Services: Determines if companies primarily earn through service fees for recycling or remanufacturing batteries.

Sales Revenue from Selling Recycled or Repurposed Battery Packs: Evaluates if direct sales of recycled or repurposed batteries are a significant income source.

Revenue from Partnerships and Collaborations: Looks at income generated through strategic partnerships and collaborations with other companies.

Revenue from Licensing or Technology Transfer Agreements: Considers income from sharing proprietary technology or processes with other entities.
Revenue from Consulting or Advisory Services: Assesses the role of consultancy services within the industry as a revenue stream.
Revenue from Value-added Services like Battery Testing or Certification: Explores income from additional services that add value to the primary offerings, like battery testing.
Revenue from Selling By-products or Secondary Materials: Investigates if the sale of by-products or secondary materials derived from recycling processes contributes to the revenue.
This question helps identify the diverse income streams and financial strategies employed by companies in this sector, which is crucial for understanding their business sustainability and growth potential.

2.4 Data Analysis

Quantitative data from the questionnaires was analyzed using Google docs and SPSS statistical tools to identify patterns, trends, and correlations. This involved calculating frequencies, percentages, and using inferential statistics to draw conclusions about the broader industry based on our sample.
Qualitative data in this study was analyzed using content analysis, a method adapted to suit the closed-ended nature of the questionnaire. In this approach, each question itself served as a code, with the responses categorized under corresponding themes such as strategies, challenges, and innovations. This method was particularly effective given the absence of open-ended questions in the questionnaire. Through this content analysis, valuable insights were gained into the various strategies employed, the challenges faced, and the innovations emerging within the industry. This analysis was instrumental in comprehensively understanding the broader operational context of these companies, shedding light on the intricate dynamics at play in the EV Li-ion battery sector.
The mixed-methods approach of this study, blending questionnaire responses with targeted LinkedIn research, resulted in a substantial dataset. From this, 12 complete responses were collected, representing a robust sample size relative to the overall population in the European EV battery 2nd use. This number of responses offers a comprehensive perspective on the sector, underpinning the study's findings.
The data analysis in this study was performed using SPSS software, focusing primarily on descriptive statistical methods. This involved organizing and summarizing the data to provide clear insights into the patterns and trends observed within the dataset. The analysis did not extend to calculating detailed statistical measures like mean, median,

or standard deviation. Instead, it concentrated on categorizing and interpreting the responses to better understand the current practices, challenges, and perspectives in the field of EV battery recycling and repurposing in Europe.
The descriptive analysis laid the foundation for more advanced inferential statistical methods that could be used in future research on this topic.

2.4.1 Ethical Considerations and Data Security

In this study, ethical considerations were a top priority to ensure the integrity and credibility of our research. Central to our ethical approach was obtaining informed consent from all participants. This involved communicating the study's purpose, the nature of their involvement, and their rights, including the right to withdraw from the study at any time without any consequences.
Ensuring confidentiality was another critical aspect of the ethical approach. To this end, all collected data were anonymized. Personal identifiers were removed or altered, and any information that could potentially lead to the identification of a participant was treated with the utmost confidentiality.
Measures for data security were implemented. Electronic data was stored on secure, password-protected accounts with restricted access. Ethical implications of the research findings were considered, focusing on their potential impact on participants and the broader community.

3. LITERATURE REVIEW

The purpose of this chapter is to define and describe the motivation and methodology of the literature review conducted for this thesis. The literature review's primary aim is to situate the thesis within the existing body of research, identifying pertinent academic resources that align with the thesis's focus. Central to this exploration are key terms including:
Circular Economy,
EV
Business Models,
Li-ion/Lithium-ion,
Batteries,
Recycling, Remanufacturing, Repurposing, and Refurbishment.

This focus was essential to refine the vast array of existing knowledge in major web databases, directing the analysis toward areas most relevant to the research objectives. In undertaking this literature review, the goal was to clarify the usage of these key terms and to understand the specific relationships, if any, that exist between them. It's important to note that this exploration did not encompass literature from all fields of knowledge; additional filters were applied to confine the research to the specified fields. The scope of these limitations was to narrow down the amount of available knowledge, ensuring that the analysis remained focused and relevant to the thesis's research plan. This methodical approach was designed to sift through the wealth of information and highlight literature that not only aligns with the key terms but also contributes significantly to the specific context and goals of the thesis.

3.1 Academic Research Methods

In the pursuit of a comprehensive understanding of the business models in the circular economy for second-use EV batteries in Europe, two predominant academic databases were employed: Scopus and Google Scholar. These platforms were chosen for their extensive coverage of scholarly literature, encompassing a wide range of disciplines that intersect with our research focus.

Scopus, known for its detailed indexing and citation-tracking features, provided a robust set of publications, including peer-reviewed articles, conference papers, and book chapters. The search strategy in Scopus was meticulously designed to capture literature

pertaining to our key terms: Circular Economy, Business Models, Li-ion/Lithium-ion, Batteries, and Recycling/Remanufacturing/Repurposing/Refurbishment. The results from Scopus are systematically compiled in which delineates the number of publications, their type, and the distribution across various disciplines.

The Scopus search string **"TITLE-ABS-KEY (("business model*" OR "economic model*" OR "financial model*") AND ("remanufacture*" OR "recondition*" OR "refurbish*" OR "reuse*" OR "recycle*" OR "second life*") AND ("battery*" OR "lithium-ion battery*") AND ("circular economy*") AND ("EV*" OR "Electric Vehicle*"))"** yielded 24 articles. The results are shown in Appendix C.1 The initial screening involved reviewing titles to exclude irrelevant studies. Subsequently, the abstracts and conclusions of the remaining articles were analyzed for strong relevance to the research theme. Papers with significant relevance were read thoroughly, ensuring that the final selection provided insightful contributions to the research topic, particularly in the context of business models in EV battery recycling and remanufacturing within the circular economy.

Similarly, Google Scholar, with its broader and more inclusive range of sources, complemented the Scopus search by providing access to a wider array of scholarly articles, The findings from Google Scholar are organized in summarizing the volume and nature of the relevant literature identified.

The search string **"business model" AND ("recycle" OR "remanufacture" OR "repurpose" OR "reuse") AND ("EV" OR "Electric Vehicle") AND "Circular Economy" AND ("batteries" OR "Li-ion Battery" OR "Li-ion Battery")** was used on Google Scholar to explore the intersection of business models, recycling, remanufacturing, repurposing, and reuse in the context of electric vehicles and circular economy. This comprehensive search yielded 229 results across 22 pages. The process involved selectively reading titles for relevance and discarding non-English resources to focus on the most pertinent studies for the research topic. The final list of relevant articles, after this careful screening, is presented in Appendix C.2.

An interesting observation from the analysis of both databases is the presence of overlapping findings. Common themes, recurring research areas, and shared conclusions from the two databases underscore the convergence in the academic discourse on this topic. However, to avoid redundancy and to maintain a sharp focus on novel insights, common findings that did not add significant value or new perspectives to our research were omitted from detailed discussion.

The tables capture the breadth and depth of research in this area, reflecting the multidisciplinary nature of the topic. They serve as a foundation for identifying gaps in

literature, understanding prevailing trends, and determining the direction of future research in the field. This structured approach to reviewing literature ensures that our research is grounded in a comprehensive understanding of existing knowledge, while also paving the way for exploring uncharted areas within the domain of circular economy business models for second-use EV batteries in Europe.

In this thesis, grey literature serves as a complementary resource to academic research, providing practical insights and contextual depth. Reports from the International Energy Agency and the European Commission, along with official company reports, enhance the study by offering real-world data, industry perspectives, and policy frameworks. These non-academic sources help validate and broaden the understanding gained from scholarly literature, ensuring a well-rounded analysis of the EV battery recycling and remanufacturing industry.

3.2 Key Findings

The literature review on the topic of business models for the second life of Electric Vehicle (EV) batteries reveals a field that is still in its nascent stages, with more theoretical explorations than practical applications. The review has identified several key findings that underline the complexities and challenges in this emerging domain. These findings are critical to understanding the current state of the industry and the potential directions for future research and development.

1. Lack of Standardization and Official Strategy One of the major challenges identified in the literature is the absence of a standardized process for remanufacturing EV batteries. This lack of standardization poses a significant hurdle for companies attempting to develop scalable and efficient business models. Without uniform guidelines or processes, companies face difficulties in optimizing operations, ensuring quality, and achieving cost-effectiveness. The European Union is reportedly working on developing a 'battery passport', which could potentially address this issue by providing a standardized framework that details the history, composition, and health of EV batteries, thereby facilitating better management and repurposing [9].
2. Uncertainty about Battery Lifespan Another significant issue highlighted is the uncertainty surrounding the lifespan of EV batteries. There is limited information on how long these batteries can effectively function in their second life, which creates challenges for companies in predicting the viability and profitability of their business models. This uncertainty affects investment decisions and the development of long-term strategies for battery repurposing and recycling [10].

3. Ambiguity in Second Life Applications While there is acknowledged the potential for second life applications of EV batteries, such as in stationary energy storage or power backups, there is still considerable uncertainty regarding the economic viability and market demand for these applications. This uncertainty stems from factors like the evolving technology of batteries, changing market dynamics, and the yet-to-be-established secondary markets for used EV batteries [9].

4. Limited Consumer Awareness There is a noticeable gap in consumer awareness regarding the closed-loop lifecycle of batteries. The general public's understanding of the potential for battery repurposing and recycling is limited, which affects the market demand for second life battery applications and recycling initiatives [11].

5. Influence of Battery Ownership Models Different battery ownership models, such as financial leasing and battery leasing, along with inter-industry partnerships and government support, are significant factors influencing the end-of-life pathways for batteries. These models can determine whether batteries are returned for repurposing or recycling, thereby impacting the supply chain for second-life batteries [12].

6. Perceptions of Battery Retrieval as a Cost Many companies view the retrieval and repurposing of lithium-ion batteries as an additional cost rather than a value-adding activity. This perception is a major barrier to the development of circular economy models in the battery industry. It reflects a short-term view that overlooks the potential long-term benefits and sustainability gains from battery repurposing and recycling [13].

7. Theoretical Business Models Versus Practical Implementation While there is considerable discussion in academic literature about potential business models for second life batteries, there is a gap in the practical implementation of these models. The theoretical models often do not account for the real-world challenges and dynamics of the market, leading to a disconnect between academic research and industry practices [14].

8. Potential for Policy and Regulatory Interventions The literature suggests a strong potential for policy and regulatory interventions to facilitate the development of second life battery models. Government policies, incentives, and regulations can play a crucial role in creating a conducive environment for businesses to invest in battery repurposing and recycling [15].

9. Evolving Technological Landscape The rapidly evolving technology of EV batteries poses both opportunities and challenges for second-life applications. While advancements in battery technology can enhance the performance and feasibility of second life batteries, they also render existing models obsolete more quickly, adding to the complexity of developing sustainable business models [16].

These findings underscore the multifaceted challenges and opportunities in the realm of second life EV batteries. They highlight the need for coordinated efforts among various stakeholders, including manufacturers, policymakers, researchers, and consumers, to address these challenges and harness the potential of this emerging field.

4. DATA ANALYSIS

This chapter presents a detailed analysis of the data collected in our study, focusing on understanding the trends, relationships, and patterns within the European market for second-life use of electric vehicle (EV) batteries. The data encompasses a diverse range of variables, including company characteristics, business models, practices in battery recycling and repurposing, and the various challenges and opportunities within the industry.

The primary objective of this chapter is to delve into the quantitative and qualitative data gathered through our meticulously designed questionnaire, which was distributed to a wide array of industry stakeholders across Europe. The responses obtained provide a rich and comprehensive dataset that allows for a multifaceted analysis of the current state and future prospects of the EV battery second-life sector.

Our analysis employs a combination of statistical techniques to ensure a robust examination of the data. Descriptive statistics will first be used to provide an overview of the dataset, offering insights into basic trends and distributions. This step is crucial for establishing a foundation for more advanced analyses and for ensuring an understanding of the general characteristics of the data.

Additionally, qualitative analysis will be conducted by examining the patterns and tendencies in the provided answers. This analysis aims to extract deeper insights and understandings from the responses, exploring themes such as strategic approaches, operational challenges, and success drivers within the EV battery second-life sector. The focus will be on interpreting the nuances and implications of the quantitative data to uncover underlying trends and perspectives among industry stakeholders.

This chapter also pays close attention to the ethical considerations involved in data analysis. All data have been anonymized and handled with utmost confidentiality to protect the privacy and integrity of the respondents. The identities of the respondents and their companies are kept anonymous, as this has no bearing or effect on the analysis part. This approach ensures that the focus remains solely on the data's content rather than on the entities providing it. Moreover, the analysis and interpretation of data are conducted with a commitment to objectivity and transparency, ensuring that the findings and conclusions drawn are reliable and can contribute significantly to the existing body of knowledge in the field. This careful handling of data underscores our commitment to ethical research practices and the respect for the confidentiality of all participants involved in the study.

In summary, this chapter aims not only to analyze and interpret the data collected but also to build a comprehensive understanding of the current dynamics and future potential of the EV battery second-life market in Europe. The insights derived here are expected to be instrumental for industry stakeholders, policymakers, and academic researchers, offering a well-rounded perspective on this evolving and crucial sector.

4.1 Industry Analysis

The data analysis of the industries participating in the questionnaire reveals significant insights into the current landscape of companies involved in the second-life use of EV batteries. The questionnaire, aimed at understanding the distribution of business activities in this sector, highlights the diversity and specialization within the industry. The results are presented in the Fig 4.1

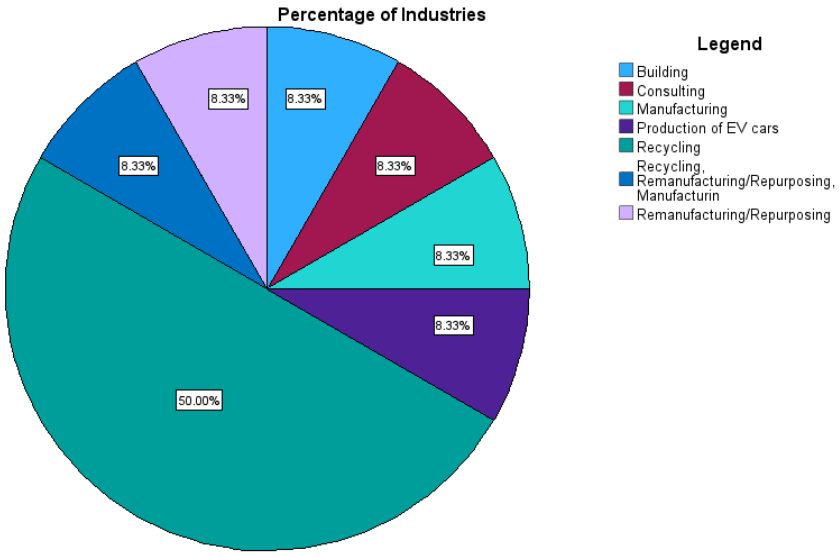

Figure 4.1 Industry Analysis

Dominance of the Recycling Sector

Notably, the recycling field dominates, accounting for half of the participants. This 50% representation underscores the recycling industry's crucial role in the EV battery life cycle. Recycling not only addresses environmental concerns but also plays a significant role in the sustainable management of battery materials. The high percentage of companies involved in recycling indicates a growing awareness and response to the need for sustainable disposal and material recovery methods for EV batteries.

Variety and Specialization within the Industry

Equally noteworthy is the distribution of the remaining 50% among various specialized fields, each representing 8,33% of the participants. This includes building, remanufacturing/repurposing, production of EV cars, consulting, battery manufacturing, and a company involved in both recycling and remanufacturing of batteries. The presence of these sectors demonstrates a multifaceted approach to the EV battery lifecycle, from production to end-of-life management.

Interestingly, two recycling companies reported involvement in additional activities such as licensing technology and active material development and production. This diversification within the recycling sector illustrates its dynamic nature and its evolution beyond traditional recycling processes. These additional activities suggest a move towards more integrated and innovative approaches in battery lifecycle management, potentially enhancing the value extracted from used batteries and creating multiple revenue streams.

A broad perspective from diverse participants, and the varied representation from different sectors, such as EV production and consulting, enriches the research with a broad spectrum of perspectives. This diversity is beneficial as it provides a holistic view of the industry. The presence of companies across different stages of the EV battery life cycle, from manufacturing to consulting, indicates a comprehensive engagement with the challenges and opportunities in the field.

Implications and Insights from the Study

The results depicted in Fig 4.1 not only illustrate the current state of industry involvement but also provide insights into potential areas for growth and collaboration. The high percentage of recycling companies highlights an area of significant interest and activity, possibly reflecting market demands and regulatory pressures for sustainable practices. The involvement of companies in production, consulting, and remanufacturing/repurposing indicates a growing ecosystem around EV batteries, pointing to opportunities for innovation and sustainable business models.

The questionnaire results highlight the importance of considering the entire ecosystem in developing strategies for the EV Li-ion second-life sector. The involvement of a wide range of industries suggests that solutions for sustainable battery use and disposal require collaborative efforts and integrated approaches. This comprehensive view is crucial for developing policies, business models, and technologies that effectively address the challenges of EV battery lifecycle management.

In conclusion, the analysis of the industry participation in the questionnaire paints a picture of an evolving sector, where recycling remains central but is increasingly supported by a range of specialized and complementary activities. This diversity not only enriches the research but also points to a dynamic and multifaceted industry, poised to address the complex challenges of sustainable EV battery management.

4.2 Country Analysis

The geographical distribution of the responses from various European countries to the questionnaire provides a valuable perspective on the diverse approaches and practices in the EV battery second-life use and recycling industry across Europe. The participation of companies from Germany, Belgium, Switzerland, Finland, France, Italy, and Sweden offers a snapshot of the industry's landscape in these regions.

Table 4.1 List of Countries

Country	**Participants**
Belgium	3
Finland	1
France	1
Germany	2
Italy	2
Sweeden	1
Switzerland	2
Total	12

The results are presented in the Fig 4.2

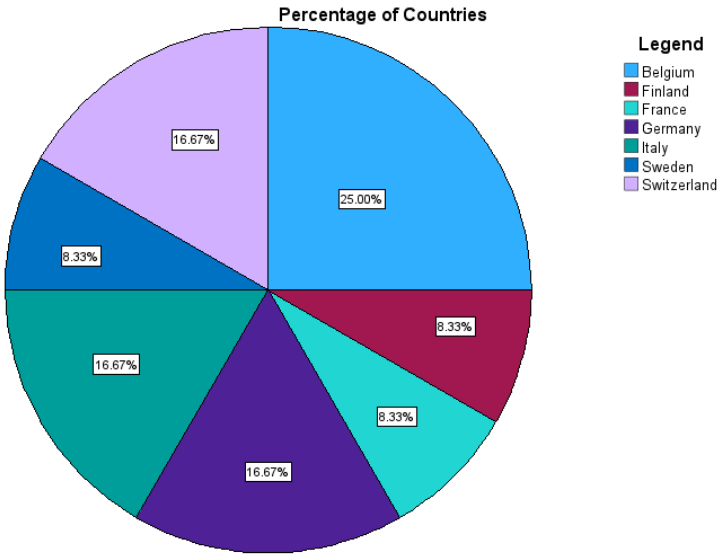

Figure 4.2 Analysis of participated countries

Germany's Participation

Germany's involvement is particularly noteworthy, given the country's significant automotive industry and its commitment to environmental sustainability [17]. With 16,67% of the responses coming from Germany, it reflects the country's active engagement in developing and implementing EV technologies and recycling processes. Germany's strong automotive sector, coupled with its focus on sustainable practices, positions it as a key player in the EV battery lifecycle.

Belgium's Leading Role

Belgium, contributing the largest proportion of responses at 25%, indicates a robust involvement in the EV Li-ion second-life sector. This high level of engagement might be attributed to Belgium's strategic position in Europe, its well-developed industrial base, and its commitment to environmental policies [18]. Belgium’s significant participation underscores its potential as a central hub for EV battery recycling and remanufacturing activities in Europe.

Switzerland and Italy

Switzerland and Italy, each accounting for 16,67% of the responses, demonstrate their notable presence in the EV Li-ion second-life sector. Switzerland’s focus on high-technology and precision manufacturing, along with its strong environmental policies, might be contributing factors to its involvement in the industry [19]. Italy's participation

reflects its growing interest in sustainable automotive solutions and the development of a circular economy in the EV sector [20].

Finland, France, and Sweden

Finland, France, and Sweden, each with 8,33% of the responses, show a balanced and significant involvement in the field. Finland's participation might be driven by its focus on technology and innovation, particularly in clean energy and sustainability [21]. France's involvement is indicative of its strong automotive industry and its commitment to reducing carbon emissions [22]. Sweden, known for its environmental leadership and sustainable practices, demonstrates its active role in the advancement of EV battery technologies and recycling.

Reflection on Regional Diversity The participation from these countries provides insights into the regional diversity in the approach to EV battery recycling and second-life use. It highlights how different European nations are contributing to the development of sustainable practices in the EV sector. The varied responses from these countries also suggest a wide range of business models, regulatory frameworks, and technological advancements being employed across Europe.

In summary, the analysis of the countries participating in the questionnaire underscores the importance of a European-wide perspective in understanding the EV battery second-use sector. The diversity in participation from Germany, Belgium, Switzerland, Finland, France, Italy, and Sweden highlights the varied approaches and contributions of these countries to the sustainable management of EV batteries. This geographical distribution offers a comprehensive view of the European efforts in advancing the EV battery industry, fostering opportunities for collaboration, research, and policy development across the continent.

4.3 Strength Analysis

The descriptive analysis of strength analysis, aimed at understanding the main strengths of business models in the recycling and remanufacturing sector, offers a revealing glimpse into the priorities and strategic focuses of companies in this evolving industry. The responses, gathered from a diverse range of companies, shed light on the critical elements that these organizations believe contribute to their success and resilience in the market. The results are shown in Fig 4.3

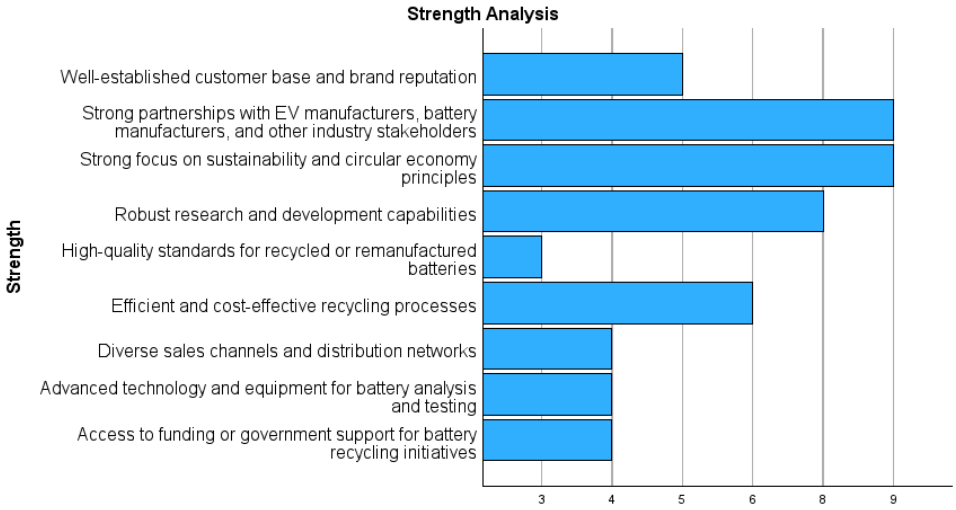

Figure 4.3 Strength analysis

Emphasis on Strong Partnerships and Sustainability

A significant finding from the analysis is the prominent emphasis on strong partnerships and a focus on sustainability, with 9 companies (75%) identifying these as their key strengths. This underscores a growing trend in the industry towards collaborative efforts. The importance of partnerships – be it with OEMs, suppliers, customers, or research institutions – points to a recognition that complex challenges in recycling and remanufacturing can be more effectively addressed through collective efforts. Moreover, the focus on sustainability reflects a broader, more environmentally conscious approach that is becoming increasingly vital in business strategies, resonating with global efforts to combat climate change and promote a circular economy.

The integration of partnerships in business models, especially within the burgeoning field of EV Li-ion battery recycling, repurposing, reusing, and remanufacturing, is vital for industry advancement. This notion is strongly supported by the responses from industry participants in a recent questionnaire. The data reveals a significant trend towards collaboration between companies and other industries, highlighting the pivotal role of inter-industry partnerships in enhancing business models related to EV Li-ion batteries.

Additionally, we inquired about the degree to which participants' companies engage in partnerships with other industry stakeholders. The results are shown in Fig 4.4

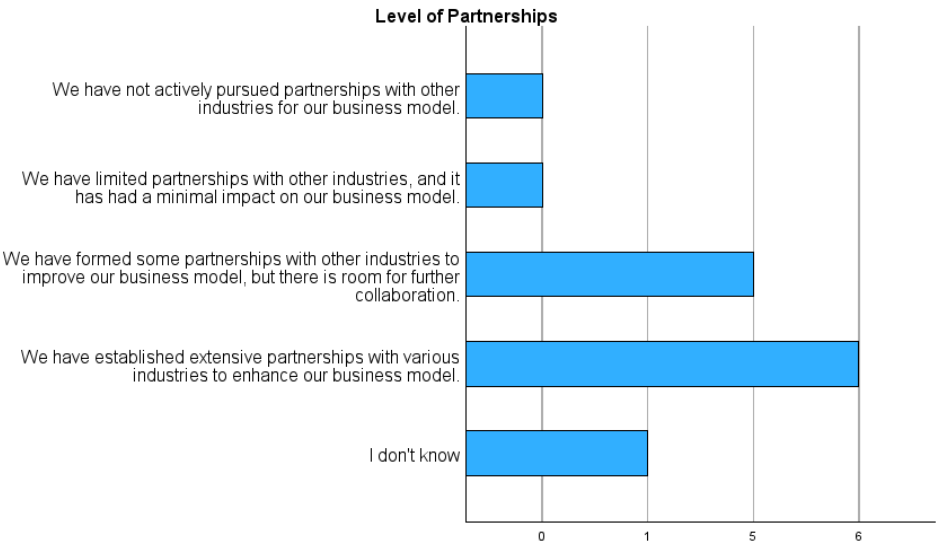

Figure 4.4 Level of Interindustry partnerships analysis

A significant 50% of the respondents indicated that they have established extensive partnerships with various industries. This demonstrates a proactive approach towards leveraging synergies across different sectors such as automotive, energy, and electronics. These collaborations are not just about enhancing operational capabilities but also about enriching the business model with diverse insights and practices. Such extensive partnerships potentially lead to innovations in recycling methods, efficient remanufacturing processes, and the development of sustainable reuse strategies. They also facilitate access to a broader market, shared R&D efforts, and the pooling of resources and expertise, which are crucial for navigating the complexities of the EV battery lifecycle.

Furthermore, 41,7% of the participants acknowledged having formed some partnerships but also recognized the potential for further collaboration. This response indicates a growing awareness among companies of the benefits that additional strategic alliances can bring. These companies might currently be engaging on a smaller scale or with a limited number of partners and thus may not fully harness the advantages of extensive inter-industry collaboration. Expanding these partnerships could lead to more robust business models, offering opportunities for scaling operations, diversifying services, and enhancing competitiveness.

Interestingly, the questionnaire found minimal instances of companies with limited or no partnerships. Only 8,3% reported not actively pursuing partnerships, while another 8,3% were unsure of their company's stance. This minimal percentage reflects a broad consensus within the industry about the importance of collaborative efforts. Companies

that have not yet engaged in significant partnerships might be missing out on critical opportunities for growth, innovation, and sustainability.

The complementary nature of these findings with the identified strength of strong partnerships underscores the industry's recognition of collaborative approaches as a cornerstone for success. Partnerships with EV and battery manufacturers, alongside stakeholders from various industries, are instrumental in developing comprehensive and innovative solutions for EV battery lifecycle management. They foster a circular economic approach, vital for environmental sustainability and business growth.

The trend of forming partnerships in the EV Li-ion second-life sector highlights a strategic shift towards collaborative innovation and sustainability. These alliances benefit not only individual companies but also the industry at large, promoting a sustainable and economically sound approach to EV battery management. The data suggests significant progress yet highlights the potential for further enhancing these networks, potentially leading to more substantial advancements and efficiencies in the sector.

Robust Research and Development (R&D) Capabilities

The industry’s inclination towards innovation is highlighted by the 8 companies (66,7%) that cited robust R&D capabilities as a main strength. This focus on R&D indicates an industry that is not just reactive but proactive in its approach, continually seeking new methods, technologies, and solutions to enhance the efficiency and effectiveness of recycling and remanufacturing processes. The investment in R&D signifies a commitment to staying ahead in a technologically advancing landscape, ensuring that the business models remain relevant, competitive, and capable of adapting to evolving market demands and regulatory landscapes.

Efficient and Cost-effective Recycling Processes

Operational efficiency is another standout aspect, with 6 companies (50%) identifying efficient and cost-effective recycling processes as a key strength. This reflects a pragmatic approach to business operations, where process optimization and cost management are crucial. Efficient recycling processes not only reduce operational costs but also enhance the company’s ability to offer competitive pricing, thereby attracting a broader customer base. This efficiency is likely a result of continuous process improvements, adoption of advanced technologies, and effective supply chain management.

Market Presence: Customer Base and Brand Reputation

The significance of a well-established customer base and a strong brand reputation is underscored by 5 companies (41,7%) citing these factors as strengths. This indicates the importance of trust and reliability in the industry. A strong brand reputation, built over time, helps in establishing a company as a reliable player in the market, essential for customer retention and attracting new business. This aspect also highlights the role of customer service and the quality of engagement companies maintain with their clients, which are critical for building and sustaining a strong market presence.

Market Reach and Technological Edge

Diverse sales channels and distribution networks, access to funding or government support, and advanced technology and equipment, each recognized by 4 companies (33,3%), reflect the multifaceted nature of the industry's strengths. These elements highlight the importance of an extensive market reach, solid financial backing, and leveraging cutting-edge technology. Access to funding or government support is crucial in an industry where initial investments can be substantial, and where regulatory compliance and environmental stewardship are key.

Focus on Quality

The commitment to high-quality standards for recycled or remanufactured batteries, cited by 3 companies (25%), is indicative of the sector's dedication to delivering superior products and services. This focus on quality not only ensures customer satisfaction but also aligns with regulatory requirements and industry standards. It is a testament to the meticulous processes and attention to detail that these companies apply in their operations.

This analysis presents a holistic view of the strengths perceived by companies within the recycling and remanufacturing sector. It illustrates an industry that is balancing technological advancement with operational efficiency, market reach, and environmental responsibility. The emphasis on strong partnerships and sustainability is particularly noteworthy, reflecting a paradigm shift in business models towards more collaborative and ecologically conscious approaches. Additionally, the focus on R&D, quality, and customer relationships indicates an industry that is not only adapting to current demands but also preparing for future challenges and opportunities.

4.4 Weaknesses and Challenges Analysis

The analysis of the challenges and weaknesses faced by companies in the second use of electric vehicle (EV) lithium-ion (Li-ion) batteries reveals a complex landscape of interlinked issues. These challenges, identified through the research, reflect critical aspects that impact economic sustainability, technological progress, and market dynamics within this emerging sector. The results are shown in Fig 4.5 and Fig 4.6

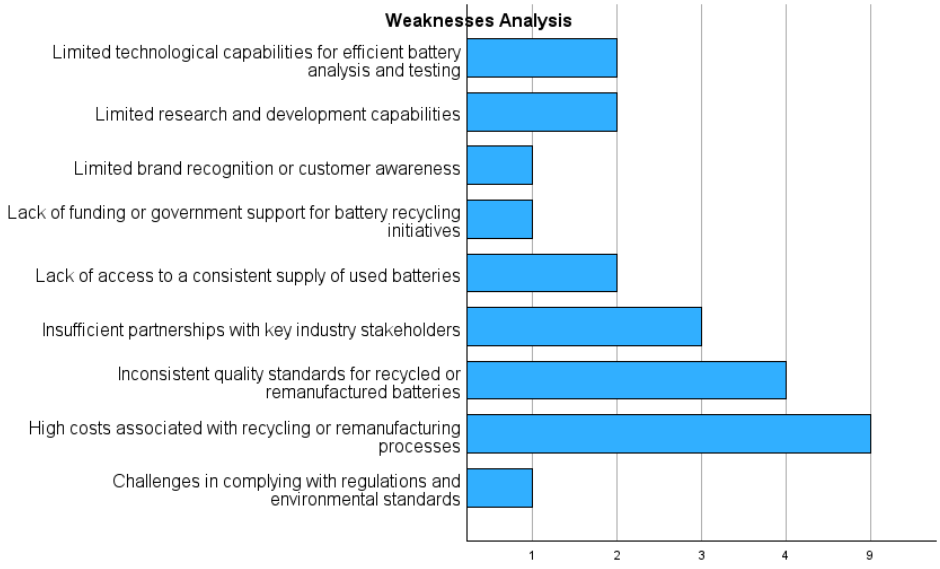

Figure 4.5 Weaknesses Analysis

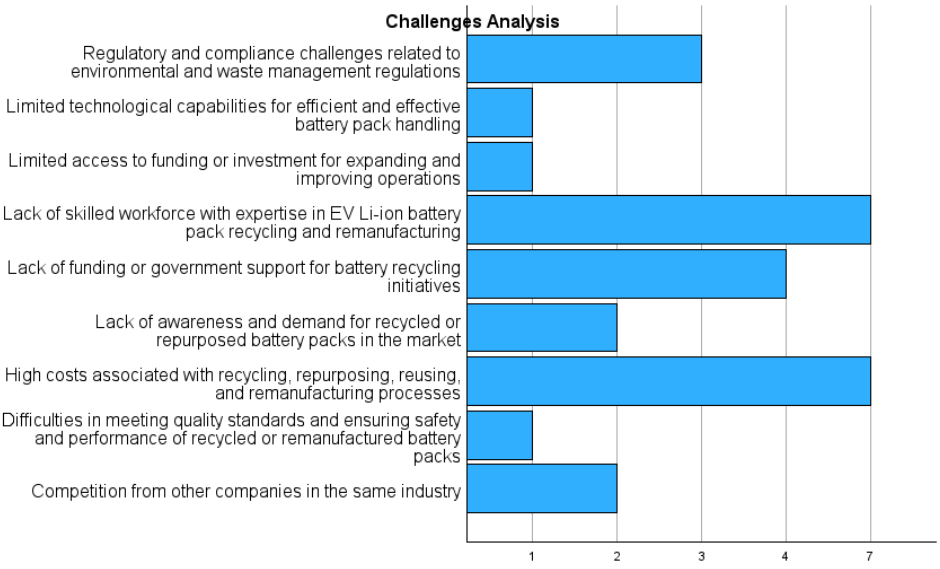

Figure 4.6 Challenges Analysis

Consistent Supply of Used Batteries

A significant portion of companies, amounting to 33,3%, report a lack of access to a consistent supply of used EV batteries as a primary challenge. The success of recycling and remanufacturing businesses heavily relies on the steady availability of these used batteries. Without a reliable supply chain, these businesses face the risk of operational disruptions and an inability to meet their production targets, which are crucial for maintaining their business operations and achieving economical sustainability goals.

The scarcity of used batteries can be attributed to the relatively young EV market, where a large number of vehicles have not yet reached the end of their lifecycle [23]. Additionally, the lack of a systematic collection and distribution network for these used batteries further exacerbates the supply issue. To address this, there is a pressing need for the development of robust inter-industry partnerships. These partnerships should ideally involve a wide range of stakeholders, including automotive manufacturers, battery producers, recycling companies, and government bodies. Such collaborations could facilitate the establishment of a well-orchestrated supply chain that ensures a steady flow of used batteries from EV owners to recycling and remanufacturing facilities.

Insufficient Partnerships with Industry Stakeholders

Insufficient partnerships within the EV battery industry, as highlighted by 27,3% of companies, underscore the importance of collaboration in overcoming the current challenges. The development of a sustainable battery lifecycle ecosystem requires the synergistic efforts of various stakeholders. Automotive manufacturers play a pivotal role in designing batteries that are easier to recycle and providing channels for their collection at the end of their lifecycle. Recycling companies, on the other hand, are crucial for processing these batteries and extracting valuable raw materials for reuse.

Effective partnerships are not just limited to the direct stakeholders but also include government bodies and regulatory agencies. These entities can facilitate the development of conducive policies, provide necessary funding, and create incentives that encourage recycling and remanufacturing activities. Additionally, collaboration with academic and research institutions can lead to technological innovations that address current operational challenges. Together, these partnerships can establish a circular economy for EV batteries, reducing waste and supporting environmental sustainability.

High Costs of Recycling/Remanufacturing

The high costs associated with recycling and remanufacturing processes are identified as a major hurdle by 58,3% of respondents. These costs stem from various factors, including the complexity of the battery structures, the need for specialized machinery, and the intricate processes required to safely dismantle and recycle batteries. Furthermore, the variability in battery chemistries and formats adds another layer of complexity, necessitating diverse processing techniques.

To mitigate these high costs, there is a need for significant investments in research and development (R&D). R&D can lead to the discovery of more efficient recycling methods, innovations in battery design that facilitate easier disassembly and recycling, and advancements in remanufacturing technologies. Moreover, the development of standardized processes and technologies can lead to economies of scale, thereby reducing operational costs.

Reducing the costs of recycling and remanufacturing is not only crucial for the profitability of these businesses but also for the broader adoption of recycled and remanufactured batteries in the market. Lower costs can translate into more competitive pricing for recycled battery materials and remanufactured battery packs, encouraging their use in various applications. This, in turn, can stimulate demand and foster the growth of a market for recycled and remanufactured batteries.

To further explore this aspect, participants were questioned about whether battery manufacturers consider the second-life use of batteries, encompassing recycling or reuse, during their design and manufacturing processes.

The consideration of recyclability and repurposability in the design of battery packs is an essential aspect that impacts the sustainability and efficiency of electric vehicle (EV) battery systems. However, the degree to which these factors are integrated into the design process varies among manufacturers. This variability in approach has significant implications for the lifecycle management of EV batteries and the overall pursuit of a circular economy in the EV sector.

According to questionnaire data, only a small fraction of battery pack manufacturers, 9,1%, consistently consider recyclability and repurposability in their design processes. This implies that for a minority of manufacturers, sustainability is a core design principle. By prioritizing recyclability and repurposability, these manufacturers are contributing to the reduction of environmental impact and enhancing the circularity of battery materials. Such designs typically facilitate easier disassembly, material recovery, and

adaptability for secondary use, thereby extending the overall lifecycle of the battery components.

In contrast, a larger proportion of manufacturers, 36,4%, sometimes integrate these considerations into their designs. This intermittent focus suggests a recognition of the importance of sustainable design but also highlights constraints or challenges that prevent a consistent approach. These constraints could include technological limitations, cost implications, regulatory factors, or market demand dynamics. For these manufacturers, recyclability and repurposability might be secondary to other design priorities such as performance, safety, or cost-effectiveness.

The most significant finding from the questionnaire is that a majority, 54,4%, of battery pack manufacturers rarely consider recyclability and repurposability in their design. This indicates a gap in the industry's commitment to sustainability. The lack of emphasis on these aspects in over half of the manufacturers could lead to challenges in end-of-life management of batteries. It may result in increased difficulties in dismantling and recycling processes, lower material recovery rates, and reduced opportunities for second-life applications.

The varying degrees of emphasis on recyclability and repurposability in battery pack design reflect the current state of the EV industry, where sustainability considerations are still evolving. While there is a growing awareness of the importance of these factors, translating this awareness into consistent design practices remains a challenge for many manufacturers. This inconsistency highlights the need for industry-wide standards and incentives that encourage the adoption of sustainable design principles. The results are shown in Fig 4.7

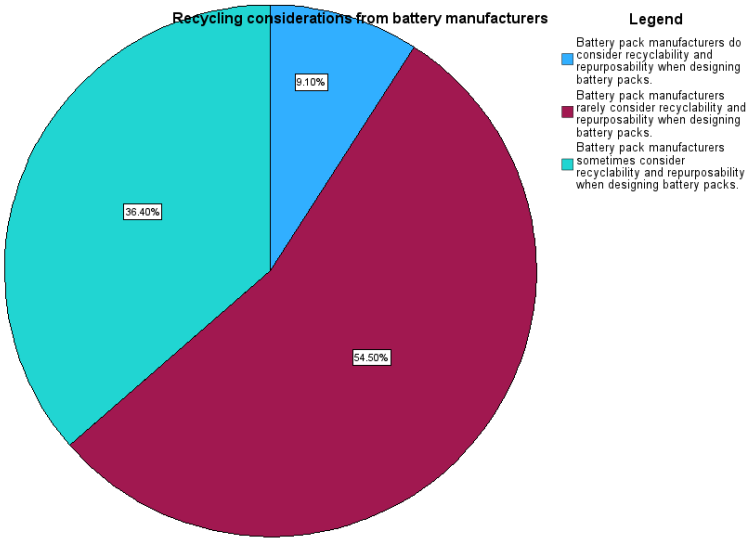

Figure 4.7 Recycling consideration from battery manufacturers analysis

The data presents a complex picture of the EV battery industry's approach to sustainable design. While there are manufacturers that prioritize recyclability and repurposability, the majority have yet to consistently integrate these considerations. This presents an opportunity for stakeholders in the EV ecosystem, including policymakers, researchers, and industry leaders, to collaborate and drive the adoption of sustainable design practices. Such collaborative efforts are crucial for aligning the industry with environmental sustainability goals and advancing the transition to a circular economy.

Technological Capabilities for Battery Analysis and Testing

A pivotal challenge, as identified by 8,3% of industry participants, is the limited technological capabilities for efficient battery analysis and testing. This limitation is reflective of the industry's relative newness and the evolving nature of battery technologies. The ability to accurately assess the condition and residual value of used batteries is crucial for ensuring the quality and safety of recycled and remanufactured products. Advancements in technology are urgently needed to enhance the efficiency and accuracy of these assessments, enabling companies to reliably determine the viability of batteries for second-life applications or recycling. Investment in R&D for developing advanced diagnostic tools and testing methodologies is imperative to overcome this challenge.

Inconsistent Quality Standards

A significant portion of companies, amounting to 36,4%, identified inconsistent quality standards as a critical weakness. This aligns with findings from the literature review, which highlighted a lack of standardization across the industry. Uniform quality standards are essential for ensuring the reliability and market acceptance of recycled and repurposed batteries. The establishment of such standards would facilitate mutual trust among industry players, regulators, and consumers, and would pave the way for a more cohesive and efficient market. The development of these standards requires collaborative efforts among industry stakeholders, including manufacturers, recyclers, policymakers, and standardization bodies.

Lack of Funding or Government Support

The role of funding and government support is vital in nurturing the growth and sustainability of the EV battery recycling sector. However, 9,1% of companies pointed out a lack of such support, which is critical for meeting environmental sustainability requirements and fostering innovation. Governmental incentives, subsidies, and policy frameworks can significantly bolster the industry, encouraging investment and

innovation. Such support is not only crucial for individual businesses but also for the broader goal of establishing a circular economy for EV batteries.

Awareness and Demand for Recycled/Repurposed Batteries

Raising awareness and demand for recycled or repurposed batteries is another challenge, cited by 16,7% of respondents. Despite the environmental and economic benefits of using recycled batteries, public and industry awareness remains limited. Efforts to educate consumers and businesses about the advantages of recycled and repurposed batteries are needed to expand the market. Initiatives could include information campaigns, partnerships with EV manufacturers

In summary, the 2nd use of EV batteries sector is navigating a myriad of challenges that span supply chain issues, technological advancements, market dynamics, regulatory compliance, and workforce development. Addressing these challenges requires a coordinated effort from industry stakeholders, policymakers, and educational institutions. By tackling these issues, industry can advance towards a more sustainable, efficient, and economically viable future.

4.5 Policies and Regulations

The questionnaire data reveals the diverse range of regulations and policies that companies in the electric vehicle (EV) Li-ion battery sector adhere to, reflecting the multifaceted approach necessary to maintain economic sustainability in this industry. These regulatory measures are crucial in shaping business models that are not only environmentally friendly but also economically viable. The results are shown in Fig 4.8

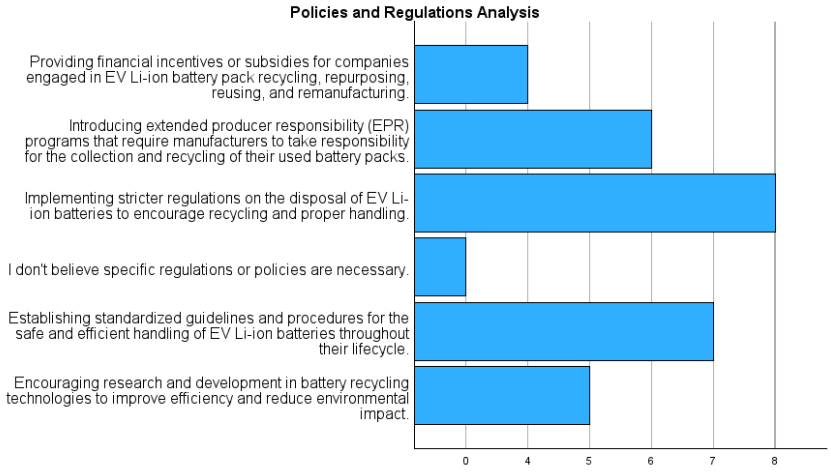

Figure 4.8 Policies and Regulations Analysis

Stricter Disposal Regulations

A significant majority of the companies, 72,7%, are implementing stricter regulations on the disposal of EV Li-ion batteries. This is a critical step toward ensuring proper handling and recycling of these batteries. Stricter disposal regulations help prevent environmental damage and encourage the development of a systematic recycling infrastructure. These regulations can also drive innovation in recycling technologies and processes.

Financial Incentives and Subsidies

Over a third of the companies, 36,4%, identified financial incentives or subsidies as a key regulatory measure. Financial incentives can significantly lower the entry barrier for new companies in the recycling sector and support existing businesses in scaling up their operations. Subsidies can offset the high initial costs associated with setting up recycling facilities and purchasing advanced machinery [24].

Standardized Guidelines and Procedures

Establishing standardized guidelines and procedures, as reported by 63,6% of companies, is essential for the safe and efficient handling of EV batteries. Standardization can lead to more uniform practices across the industry, making it easier to train personnel, ensure safety, and maintain quality control. It can also facilitate international trade in recycled materials.

Research and Development Encouragement

Approximately 45,5% of companies emphasize the importance of encouraging research and development in battery recycling technologies. Innovations from R&D, like improved material recovery and easier battery disassembly, can significantly cut costs and give companies a competitive edge in the fast-evolving industry. This investment in R&D goes beyond environmental responsibility; it's a strategic decision with real economic benefits.

Extended Producer Responsibility (EPR) Programs

Over half of the companies, 54,4%, acknowledge the introduction of EPR programs as a significant regulatory tool. EPR programs require manufacturers to take responsibility for the collection and recycling of their used battery packs. This approach incentivizes manufacturers to design batteries that are easier to recycle and encourages them to invest in recycling infrastructure.

The responses reflect a comprehensive approach towards regulations and policies in the EV Li-ion battery recycling sector. The combination of stricter disposal regulations, financial incentives, standardized guidelines, R&D encouragement, and EPR programs forms a robust regulatory framework. This framework not only ensures environmental sustainability but also bolsters economic viability, which is crucial for the long-term success of the industry.

The incorporation of circular economy principles into the operations of companies in the EV Li-ion second-life sector is a pivotal strategy for ensuring environmental sustainability and economic efficiency. The questionnaire responses indicate various strategies employed by these companies, reflecting a holistic approach to integrating circular economy practices.

4.6 Strategies

The questionnaire explores the range of regulations and policies followed by companies in the EV battery second-use sector to sustain an economically viable business model. This encompasses strategies like implementing strict disposal regulations, offering financial incentives, establishing standardized handling guidelines, promoting research in recycling technologies, and introducing extended producer responsibility programs. The analysis of these responses aims to understand how these regulatory frameworks shape business practices in recycling, repurposing, reusing, and remanufacturing of EV batteries. The results are shown in Fig 4.9

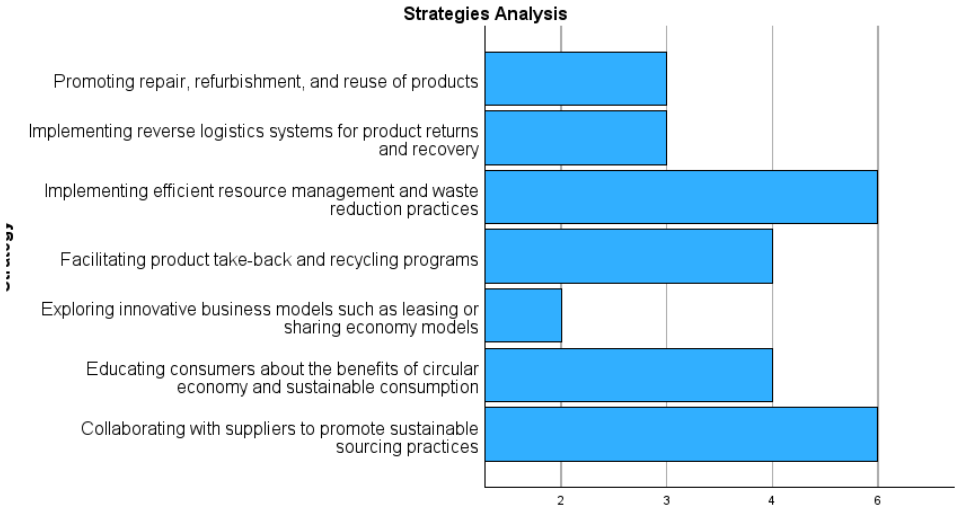

Figure 4.9 Strategies Analysis

Efficient Resource Management and Waste Reduction

A significant 60% of companies prioritize implementing efficient resource management and waste reduction practices. This strategy is central to the circular economy as it directly addresses the need to optimize resource utilization and minimize waste generation. Efficient resource management involves careful planning and use of materials, energy, and other resources, reducing the environmental impact and cost. Waste reduction not only conserves resources but also reduces the burden on disposal and recycling systems.

Promoting Repair, Refurbishment, and Reuse

About 30% of the companies engage in promoting repair, refurbishment, and reuse of products. This strategy aligns with the circular economy's aim to extend the product lifecycle, thereby reducing the need for new resources and minimizing waste. Repair and refurbishment can revitalize used products, making them functional again, while reuse involves finding new applications for used products.

Facilitating Product Take-Back and Recycling Programs

Facilitating product take-back and recycling programs, a strategy used by 40% of companies, plays a crucial role in ensuring a consistent supply of batteries for sustainable operations. These programs, by recycling end-of-life products, recover valuable materials and reduce waste. Moreover, they establish a direct link between consumers and recyclers, enhancing resource recovery efficiency. This approach, as discussed in the challenges analysis section, is vital for maintaining a sustainable and efficient battery supply chain.

Collaborating with Suppliers for Sustainable Sourcing

60% of companies emphasize collaborating with suppliers for sustainable sourcing, which is not just about reducing environmental impact but also about ensuring economic sustainability. By sourcing materials and components responsibly, companies can ensure a stable, ethical supply chain, reducing risks and enhancing their brand reputation. This strategic alignment with sustainability principles can lead to long-term cost savings and market advantages, making it a key economic consideration for businesses in this sector.

Exploring Innovative Business Models

Around 20% of the companies are exploring innovative business models like leasing or sharing economy models. These models promote the utilization of products without the need for ownership, thus reducing material consumption and encouraging efficient use of resources [25]. Leasing models can lead to better product design for longevity and recyclability as manufacturers retain ownership and responsibility for the product's end-of-life.

Educating Consumers

Educating consumers about the benefits of circular economy and sustainable consumption is a strategy employed by 40% of companies. Consumer awareness is crucial for the success of circular economy practices. By educating consumers, companies can influence purchasing decisions, encourage proper disposal for recycling, and promote sustainable use of products.

Implementing Reverse Logistics

Finally, 30% of the companies implement reverse logistics systems for product returns and recovery. Reverse logistics involves the planning and management of the movement of products from consumers back to the company for recycling, refurbishment, or disposal. This system is essential for efficient product recovery and plays a vital role in circular economy operations.

In conclusion, the strategies employed by companies in the EV Li-ion battery sector to incorporate circular economy principles highlight a multi-faceted approach. From resource management to consumer education, each strategy contributes to the overarching goal of sustainable

4.7 Distribution Channels Analysis

In the evolving landscape of Electric EV batteries' recycling, repurposing, reusing, and remanufacturing, the way companies distribute their value proposition to various customer segments is crucial. This distribution strategy not only determines market reach but also impacts the overall effectiveness and sustainability of the business model. Analyzing responses from industry participants sheds light on the diverse approaches adopted to navigate through this dynamic market. The results are shown in Fig 4.10

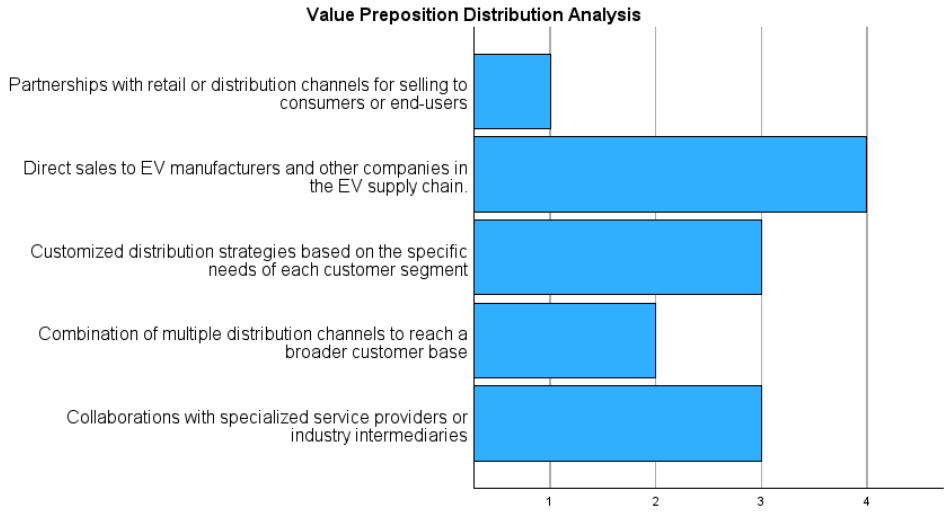

Figure 4.10 Value Distribution Analysis

Direct Sales to EV Manufacturers

The majority (57,1%) of companies in the sector opt for direct sales to EV manufacturers and companies in the EV supply chain. This approach emphasizes a straightforward, business-to-business model, capitalizing on the direct relationships with primary stakeholders in the EV industry. By dealing directly with manufacturers, these companies ensure a streamlined process, minimizing complexities and fostering a more controlled and efficient distribution of products and services. This method likely provides a robust and reliable revenue stream, given the growing demand for EVs and the consequent need for battery-related services.

Partnerships with Retail or Distribution Channels

A smaller segment (14,3%) of businesses engages with retail or distribution channels to reach consumers or end-users. This method diversifies the customer base beyond industry players to the general consumer market. Such partnerships are essential for businesses focusing on aspects like battery refurbishment or repurposing where the product is more consumer-oriented. However, this strategy demands a comprehensive understanding of consumer needs and behaviors, necessitating more investment in market research and consumer engagement.

Collaborations with Specialized Service Providers

Almost half of the respondents (42,9%) highlighted collaborations with specialized service providers or industry intermediaries. This collaborative approach enables

companies to leverage the expertise of third parties, expanding their operational capabilities without substantial internal investment. It's indicative of an ecosystem where symbiotic relationships bolster the overall value chain, enhancing the reach and quality of services offered.

Customized Distribution Strategies

An equal proportion of companies (42,9%) use customized distribution strategies tailored to the specific needs of each customer segment. This bespoke approach demonstrates a customer-centric model, where services are fine-tuned to meet the unique requirements of different market segments. Such flexibility is crucial in a field as nuanced as battery recycling and repurposing, where the needs can vary significantly across different customers.

Multiple Distribution Channels

Lastly, 28,6% of businesses employ a combination of various distribution channels to broaden their customer base. This integrated approach merges the benefits of direct sales, partnerships, and collaborations, offering a comprehensive reach to diverse market segments. Employing multiple channels can be particularly effective in a sector characterized by varied customer needs and evolving market dynamics.

The distribution strategies in the EV Li-ion battery sector reflect a blend of direct sales, partnerships, collaborations, customization, and integrated approaches. The choice of strategy seems to be influenced by factors like the nature of the product or service, target customer segments, and the company's operational strengths. As the industry grows and evolves, these distribution strategies may further diversify, adapting to new market demands and technological advancements. Understanding and analyzing these approaches provides valuable insights into the commercial dynamics of the EV Li-ion second-life sector and underscores the importance of strategic distribution in achieving business success.

4.8 Technology Analysis

The EV batteries' recycling, repurposing, reusing, and remanufacturing industry is on the edge of transformation, largely driven by emerging technologies. Understanding the technologies that industry players anticipate will significantly improve their business models is crucial. This understanding not only highlights the current technological gaps but also guides future investments and research directions in the sector. The results are shown in Fig 4.11

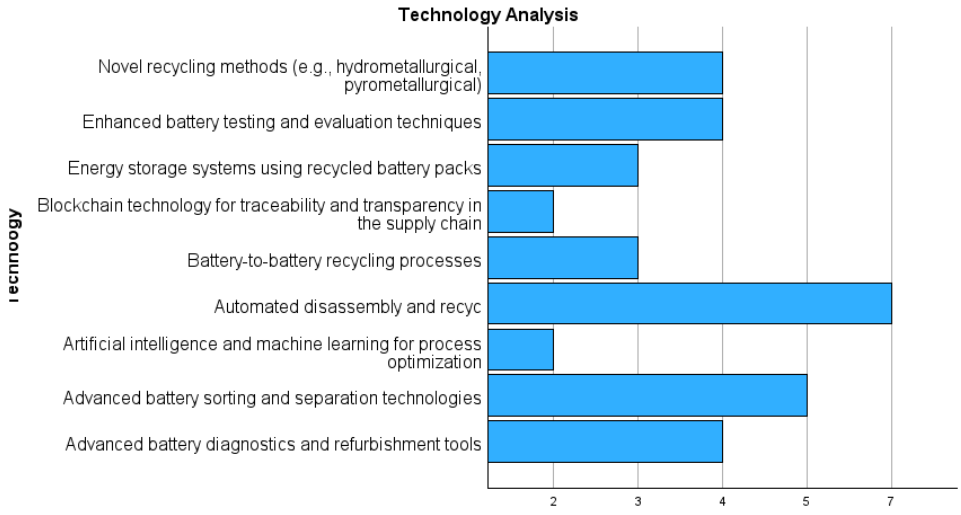

Figure 4.11 Technology Analysis

Advanced Battery Sorting and Separation Technologies

Nearly half of the respondents (45,5%) identified advanced battery sorting and separation technologies as pivotal. This technology is essential for efficiently segregating battery components, which is a critical step in recycling. Improved sorting technologies can enhance the recovery of valuable materials and reduce the environmental impact [26].

Automated Disassembly and Recycling Systems

The highest response rate was for automated disassembly and recycling systems (63,6%). Automation in disassembly can significantly speed up the recycling process, reducing labor costs and improving safety. Automated systems are also more precise, reducing the risk of damaging valuable battery components [27].

Enhanced Battery Testing and Evaluation Techniques

Improved battery testing and evaluation techniques, chosen by 36,4% of participants, are vital for assessing the health and potential reuse of EV batteries. Enhanced testing methods can accurately determine the remaining life of a battery, facilitating decision-making regarding recycling or repurposing [28].

Advanced Diagnostics and Refurbishment Tools

An equal proportion of respondents (36,4%) see advanced diagnostics and refurbishment tools as crucial. These tools can diagnose battery health more effectively

and refurbish them for extended use, thereby prolonging their lifecycle [29]. This technological advancement is critical for repurposing batterie

Novel Recycling Methods

Novel recycling methods like hydrometallurgical and pyrometallurgical processes were highlighted by 36,4% of respondents. These methods offer environmentally friendly and efficient ways to recover precious materials from batteries [30]. The academic community has been exploring these methods, emphasizing their potential in improving the recycling process.

Battery-to-Battery Recycling Processes

Battery-to-battery recycling, chosen by 27,3% of participants, involves directly recycling materials from spent batteries into new battery production. This approach can significantly reduce the environmental footprint and is seen as a sustainable method for managing battery waste.

Energy Storage Systems Using Recycled Battery Packs

The use of recycled battery packs in energy storage systems, also selected by 27,3% of respondents, presents a promising avenue for second-life applications of EV batteries. This aligns with research findings that advocate for the utilization of EV batteries in stationary storage applications, thereby contributing to a circular economy.

Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) for process optimization were identified by 18,2% of companies. AI and ML can analyze vast amounts of data to optimize recycling processes, improve battery design for recyclability, and manage the logistics of battery collection and distribution [31].

Blockchain Technology

Finally, 18,2% of respondents acknowledged the potential of blockchain technology in enhancing traceability and transparency in the supply chain. Blockchain can help track the lifecycle of a battery from production to recycling, ensuring responsible sourcing and recycling practices. This technology's role in supply chain management is a growing area of research, with studies highlighting its benefits in ensuring sustainability [32].

The feedback from industry players on emerging technologies reveals a multifaceted approach towards improving the efficiency and effectiveness of EV Li-ion batteries

recycling, repurposing, reusing, and remanufacturing. The focus on automation, advanced diagnostics, novel recycling methods, and technological innovations like AI and blockchain indicates a sector ripe for technological disruption. These technologies align well with academic research, underscoring their feasibility and potential impact. As these technologies continue to develop, they hold the promise of revolutionizing the EV Li-ion second-life sector, steering it towards greater sustainability and economic viability.

In the competitive landscape of EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing, distinctive value propositions are crucial for companies to differentiate themselves. Understanding these unique selling points offers insight into industry trends, customer priorities, and future directions for the sector.

4.9 Value Proposition Analysis

The Value Proposition Analysis section examines how companies in the EV batteries recycling, repurposing, reusing, and remanufacturing industry differentiate themselves. The focus is on evaluating key factors such as proprietary technologies, industry expertise, strategic partnerships, and proven track records in delivering quality services. This analysis aims to understand the unique selling points that set these companies apart and contribute to their competitive advantage in the market. The results are shown in Fig 4.12

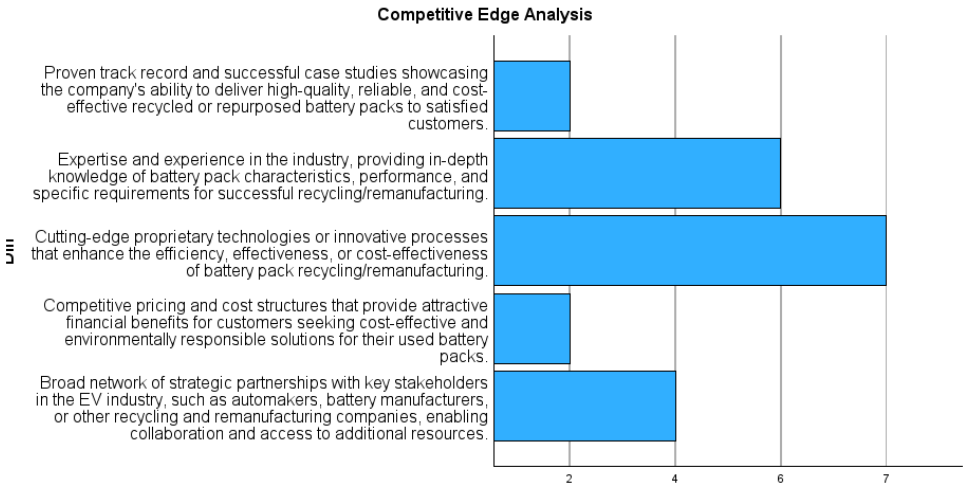

Figure 4.12 Value proposition Analysis

Cutting-Edge Proprietary Technologies

A significant majority (63,6%) of companies credit their success to cutting-edge proprietary technologies or innovative processes. These technologies enhance the efficiency, effectiveness, or cost-effectiveness of battery pack recycling and remanufacturing.

Industry Expertise and Experience

Over half of the respondents (54,4%) identified their expertise and experience in the industry as a key differentiator. This expertise provides in-depth knowledge of battery pack characteristics and recycling requirements. Companies with a rich history and deep understanding of the industry can offer tailored solutions that newer entrants may not.

Strategic Partnerships Network

Around one-third of the companies (36,4%) highlight their broad network of strategic partnerships as a differentiating factor. Collaborations with automakers, battery manufacturers, and other industry players facilitate resource sharing and innovation.

Proven Track Record and Case Studies

A smaller proportion (18,2%) of companies differentiate themselves through a proven track record and successful case studies. These companies showcase their ability to deliver high-quality, reliable, and cost-effective recycled or repurposed battery packs. Companies that can demonstrate successful outcomes through case studies can better convince potential clients of their capabilities.

Competitive Pricing and Cost Structures

Finally, competitive pricing and attractive cost structures are cited by 18,2% of respondents as a key value proposition. In a market where cost-effectiveness is increasingly important, offering financially attractive solutions can be a significant differentiator. Studies in environmental economics and sustainable business models highlight the role of pricing strategies in promoting sustainable practices among consumers. Companies that can offer cost-effective solutions without compromising on quality or environmental responsibility can appeal to a broader customer base.

The diverse value propositions identified by companies in the EV Li-ion second-life sector reflect a market that values technological innovation, expertise, strategic partnerships, proven success, and competitive pricing. Each of these elements plays a crucial role in

differentiating companies in this rapidly evolving industry. As the sector continues to grow, these value propositions will likely shape the strategies of existing and new market entrants. Companies that can effectively leverage these strengths while continuing to innovate and adapt to market needs are poised for success in the dynamic landscape of EV battery recycling and remanufacturing.

4.10 Revenue Streams Analysis

Understanding the revenue streams in the EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing industry is critical for comprehending how these businesses sustain themselves financially. This analysis delves into the various income sources identified by industry players, offering insights into the economic dynamics of this sector. The results are shown in Fig 4.13

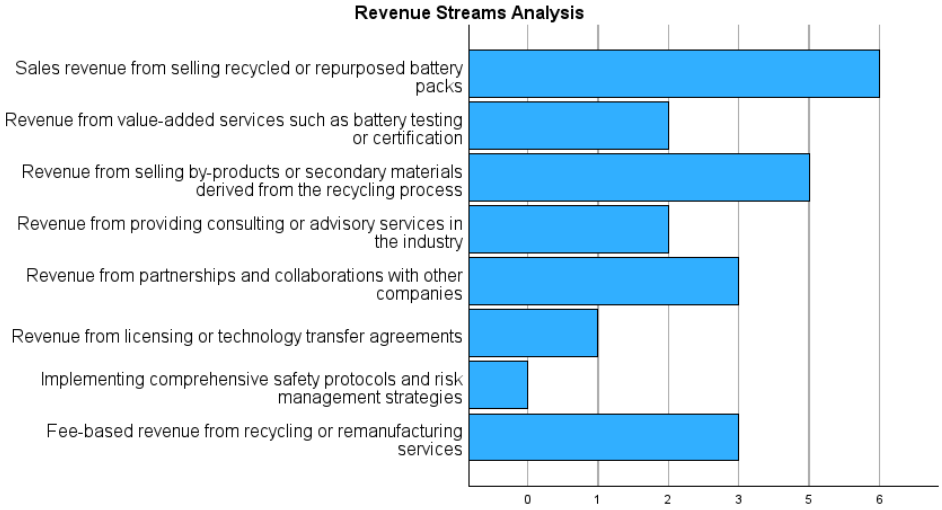

Figure 4.13 Revenue Stream Analysis

Sales Revenue from Recycled or Repurposed Battery Packs

The most prominent source of income, as indicated by 54,4% of respondents, is sales revenue from recycled or repurposed battery packs. This finding aligns with the core principle of the circular economy, where value is derived from extending the life cycle of products. Academic research supports this approach, highlighting that selling recycled products not only contributes to sustainability but also taps into new market segments sensitive to environmental issues.

Fee-based Revenue from Services

Another significant revenue stream, as per 27,3% of the participants, comes from fee-based services in recycling or remanufacturing. This model is consistent with the service-oriented approach in modern business strategies, as discussed in service marketing literature. Charging for the services provided in recycling and remanufacturing batteries ensures a steady income flow and can be scaled according to the volume of work and complexity of tasks.

Partnership and Collaboration Revenue

Equally, revenue from partnerships and collaborations with other companies forms a crucial part of the business model for 27,3% of the companies. This approach, supported by strategic management theories, emphasizes the importance of collaborative ventures and networks in creating new business opportunities and accessing new markets.

Revenue from By-Products

A notable 45,5% of companies generate revenue from selling by-products or secondary materials derived from the recycling process. This practice aligns with industrial ecology concepts, where waste from one process becomes an input for another, creating additional revenue streams and minimizing waste.

Consulting or Advisory Services Revenue

Around 18,2% of companies gain revenue from providing consulting or advisory services. This reflects the growing trend in knowledge-based revenue streams, as suggested by business consultancy literature. Companies with expertise in this niche market can capitalize on their knowledge, offering guidance and strategies to other players in the industry.

Licensing or Technology Transfer Revenue

The industry also sees income from licensing or technology transfer agreements, as reported by 9,1% of participants. This finding is underpinned by innovation and technology management research, which emphasizes the value of intellectual property in creating revenue streams through licensing and technology transfer.

Value-Added Services Revenue

Additionally, 18,2% of companies derive revenue from value-added services such as battery testing or certification. This approach is backed by quality management and

customer satisfaction literature, suggesting that offering additional, high-value services can attract clients looking for comprehensive solutions.

Safety Protocols and Risk Management

Interestingly, none of the respondents indicated revenue generation from implementing safety protocols and risk management strategies. This suggests that while these aspects are vital for operational efficiency and regulatory compliance, they are not directly perceived as revenue-generating activities in this sector.

The diverse revenue streams in the EV Li-ion battery recycling sector reflect a multifaceted approach to business sustainability. Companies in this industry are not just relying on traditional sales but are also exploring service-based, partnership-driven, and knowledge-oriented revenue models. This diversity not only ensures economic sustainability but also fosters innovation and collaboration within the industry. The alignment of these revenue streams with academic principles and business models indicates a sector that is adaptable, forward-thinking, and responsive to market needs and sustainability imperatives. As the industry evolves, these revenue streams might diversify further, offering new opportunities for growth and innovation in the dynamic field of EV battery recycling and remanufacturing.

5. CONCLUSION AND FUTURE IMPROVEMENT

As the journey through this comprehensive exploration of the European EV battery recycling, repurposing, reusing, and remanufacturing industry draws to a close, it is imperative to reflect on the insights garnered and the paths that lie ahead. This concluding chapter serves as a synthesis of the entire study, encapsulating the core findings, evaluating the methodologies applied, and offering a forward-looking perspective on the industry's future.

Embarking on this research journey, the primary aim was to delve deep into the existing business models within the European EV Li-ion second-life sector, understand the intricacies of its operational dynamics, and identify the challenges and opportunities that define its landscape. This endeavor was rooted in the recognition of the critical role that the EV Li-ion second-life sector plays in shaping a sustainable future, not just for the automotive industry but for society as a whole.

Throughout this study, various facets of the industry were scrutinized, ranging from the economic viability of business models to the technological innovations driving the sector forward. A mix of quantitative and qualitative methodologies was employed, drawing from a rich tapestry of data and insights from industry professionals across Europe. This approach not only provided a multi-dimensional view of the sector but also illuminated the diverse strategies and practices that characterize it.

As this chapter unfolds, it aims to weave together the threads of analysis from previous chapters, offering a coherent narrative of the study's findings. It will revisit the initial objectives set forth at the beginning of this research, assess how effectively these goals were met, and critically examine the methodologies that underpinned the study. Furthermore, the chapter will explore the implications of the findings for industry stakeholders, considering the potential economic, environmental, and societal impacts.

Finally, the chapter will look ahead, proposing recommendations for future research and industry practice. It will identify areas where further investigation is needed and suggest ways in which the industry can evolve and adapt to meet the challenges of tomorrow. In essence, this chapter is not just a conclusion but a gateway to future possibilities and improvements in the dynamic and ever-evolving world of EV battery recycling and remanufacturing.

5.1 Summary of Key Findings

5.1.1 Overview of the European EV Li-ion second-life sector

The European EV Li-ion second-life sector is experiencing significant growth, reflecting a broader shift towards sustainable transportation. This research has provided a detailed examination of the industry, particularly focusing on the recycling, repurposing, reusing, and remanufacturing aspects of EV batteries.

Key statistics from our questionnaire highlight the diverse nature of the industry. About 50% of the participating companies are directly involved in the recycling field, indicating a strong focus on environmental sustainability. Other sectors represented include building (8,33%), remanufacturing/repurposing (8,33%), EV production (8,33%), and consulting (8,33%). This diversity underscores the multifaceted nature of the industry and its integration across various sectors.

5.1.2 Insights on Business Models and Revenue Streams

The study delves into the business models and revenue streams that underpin the EV battery recycling and remanufacturing sector. A significant portion of the companies (54,4%) generate income from the sale of recycled or repurposed battery packs. This is complemented by fee-based revenue from recycling services (27,3%) and partnerships with other companies (27,3%). The data also reveal emerging trends, such as revenue from licensing or technology transfer agreements (9,1%) and consulting services (18,2%)

The reliance on multiple revenue streams demonstrates the sector's adaptability and its efforts to establish a robust economic foundation. The high percentage of sales revenue from recycled or repurposed batteries highlights the increasing market demand for sustainable battery solutions.

5.1.3 Identified Challenges and Technological Innovations

The study identified several key challenges facing the industry. High operational costs are a significant concern, reported by 58,3% of participants, emphasizing the need for more efficient and cost-effective recycling processes. A lack of consistent battery supply, noted by 33,3% of respondents, underscores the importance of establishing reliable supply chains. Additionally, 27,3% of companies indicated insufficient partnerships, highlighting the need for stronger collaborations across industry stakeholders.

Technological innovations were seen as vital in addressing these challenges. Automated disassembly and recycling systems, selected by 63,6% of respondents, represent a significant area for potential improvement. Enhanced battery testing and evaluation techniques (36,4%) and advanced battery diagnostics tools (36,4%) were also identified as important for advancing the industry. These innovations are crucial for increasing the efficiency, reliability, and sustainability of battery recycling and remanufacturing processes.

Furthermore, 45,5% of respondents noted the potential of advanced battery sorting and separation technologies, indicating a shift towards more sophisticated and targeted recycling methodologies. This aligns with the industry's overall trend towards embracing technology-driven solutions to improve operational efficiency and environmental impact.

In summary, the European EV Li-ion second-life sector is characterized by a diverse range of business models and revenue streams, each addressing various aspects of the battery lifecycle. The sector faces significant challenges, particularly in terms of operational costs and supply chain management. However, technological innovations offer promising solutions, signaling a bright future for the industry as it continues to adapt and evolve in response to environmental and market demands.

5.2 Evaluation of Research Objectives

5.2.1 Alignment of Findings with Initial Objectives

The primary objective of this thesis was to explore the current landscape of the European EV battery recycling, repurposing, reusing, and remanufacturing industry, with a focus on understanding the various business models, challenges, and revenue streams. The findings from the research align well with these objectives, providing a comprehensive overview of the sector and uncovering key insights that contribute to our understanding of this evolving industry.

For instance, the analysis of industry participation revealed that 50% of respondents were from the recycling sector, underscoring the prominence of recycling in the EV battery life cycle. Additionally, the diverse representation from sectors like building, remanufacturing/repurposing, and EV car production (each constituting 8,33% of respondents) highlighted the interdisciplinary nature of the industry. This diversity in participation ensured a broad perspective, aligning with the objective to capture a comprehensive view of the industry.

5.2.2 Assessment of Methodological Approach

Reflecting on the methodology of this thesis, particularly the data collection process via the questionnaire, there are several areas where improvements could be made. While the questionnaire was effective in gathering structured responses, the reliance on close-ended questions limited the depth of qualitative analysis that could be conducted. In hindsight, incorporating open-ended questions would have allowed respondents to provide broader, more nuanced answers. This approach would have significantly enriched the qualitative aspect of the study, offering deeper insights into the participants' perspectives and experiences.

Although an option for participants to write their responses was included for each question, it appears that most participants preferred selecting from the predefined choices for the sake of convenience and time efficiency. This tendency underscores the importance of balancing the need for detailed responses with the ease of participation for respondents. Future questionnaires could benefit from a more strategic blend of open and closed questions, carefully considering the respondent's time and effort.

Another area for improvement is the structuring of the questionnaire. Some questions, particularly those addressing challenges and weaknesses, exhibited considerable overlap. Combining such questions could have streamlined the survey, making it more concise and focused. A shorter and more targeted questionnaire might encourage higher response rates, as potential participants are often deterred by lengthy surveys.

The length of the questionnaire in this study was somewhat extensive, which might have impacted the number of responses received. Lengthy questionnaires can lead to respondent fatigue, potentially affecting the quality of the responses or dissuading potential participants from completing the survey. Future research endeavors could focus on creating more succinct, yet comprehensive, questionnaires to facilitate higher response rates and more engaged participation.

In conclusion, while the questionnaire served as a valuable tool for data collection in this study, these reflections and potential improvements highlight the importance of continuously evaluating and refining research methodologies. Adapting the questionnaire design to include a balanced mix of question types and ensuring its length is manageable can lead to richer data collection and more robust research outcomes.

The methodological approach combined quantitative data analysis with qualitative insights, primarily gathered through a questionnaire distributed to industry professionals. This mixed-methods approach was effective in capturing both the

numerical data required for a thorough analysis and the nuanced insights that can only be gleaned from qualitative responses.

The use of statistical tools like SPSS provided clarity and precision in analyzing data. For example, the study's analysis of business strengths and weaknesses, using numerical values), allowed for a clear and quantifiable understanding of what companies consider their key attributes. The fact that 17,31% of companies identified strong partnerships and focus on sustainability as their main strengths is a testament to the industry's commitment to collaborative and environmentally responsible practices.

5.2.3 Reflection on the Scope and Limitations of the Study

While the study effectively achieved its objectives, it's important to recognize certain limitations. The sample size was appropriate for an initial analysis and offered valuable insights. However, a significant portion of the responses, about 50%, came from the recycling sector. This concentration means that the remanufacturing sector was less represented, possibly leading to a skewed emphasis on recycling perspectives. This imbalance may affect the comprehensiveness of the findings, as insights from the remanufacturing sector weren't as prominently featured. Future studies could aim for a more balanced representation to capture a wider spectrum of the industry.

Additionally, the recruitment of participants through LinkedIn might have introduced a selection bias, possibly attracting respondents who are more digitally active and engaged with professional networks. This could mean that certain voices or perspectives from less digitally-engaged sectors of the industry might be underrepresented in the study.

Despite these limitations, the study's findings provide valuable insights into the European EV Li-ion second-life sector, particularly in understanding the varied business models and key challenges faced by the industry. The study also highlights the necessity for further research, especially in expanding the sample size and diversifying recruitment methods to capture a more representative cross-section of the industry. Future research could build on these findings, exploring more in-depth the emerging trends and innovations that are shaping this rapidly evolving sector.

5.2.4 Implications for Industry Stakeholders

The study's findings have significant implications for various stakeholders in the EV Li-ion second-life sector, including manufacturers, policymakers, and consumers. For manufacturers, the insights into business models and revenue streams point to the necessity of diversifying income sources. As indicated by the data, 54,4% of companies

generate sales revenue from selling recycled or repurposed battery packs, while 27,3% rely on fee-based services. This diversity in revenue streams is crucial for business resilience in a rapidly evolving market.

Policymakers can also glean valuable insights from this research. The finding that 72,7% of companies are implementing stricter regulations on EV Li-ion battery disposal suggests a pressing need for robust policy frameworks. These policies should encourage recycling and proper handling, thus contributing to a circular economy. Furthermore, 63,6% of companies are following standardized guidelines for handling EV batteries, highlighting the need for consistent and comprehensive regulatory standards across Europe.

For consumers, this research underscores the growing importance of sustainable consumption. The fact that 40% of companies are educating consumers about the benefits of circular economy practices indicates a shift towards more environmentally conscious consumer behavior. This shift is not only beneficial for the environment but also offers consumers opportunities to engage with more sustainable products and practices.

5.2.5 Significance for Environmental Sustainability

Environmental sustainability is a central theme in the EV battery recycling and remanufacturing industry. The study's findings reveal that 60% of companies are implementing efficient resource management and waste reduction practices, demonstrating a commitment to reducing environmental impact. Moreover, the emphasis on promoting repair, refurbishment, and reuse of products by 30% of companies aligns with the principles of a circular economy, further enhancing the sector's sustainability credentials.

5.2.6 Economic Repercussions and Opportunities

The economic implications of the study are multifaceted. High operational costs, identified as a challenge by 58,3% of respondents, indicate the need for industry innovation and efficiency improvements. This challenge also presents an opportunity for companies to invest in R&D and develop more cost-effective technologies.

The study also highlights potential economic opportunities in the sector. For instance, the finding that 45,5% of companies are generating revenue from selling by-products or secondary materials derived from the recycling process opens new avenues for economic growth. This not only adds to a revenue stream but also contributes to waste reduction and resource efficiency.

This research offers critical insights for industry stakeholders, highlighting the need for diversified business strategies, robust policy frameworks, and consumer education on sustainability. The findings also underscore

5.3 Recommendations for Future Research and Industry Practice

The recommendations for future research stemming from this study point towards a deeper, more nuanced exploration of the data collected. Each question posed in the research opens avenues for further investigation, revealing the complexity and interconnectedness of factors influencing the electric vehicle (EV) battery recycling and remanufacturing industry.

One vital area for future research is the investigation of the relationship between a company's geographical location and the specific challenges it faces. This exploration could uncover how factors such as local regulations, economic conditions, and access to resources vary across regions and influence the operations of companies in the EV Li-ion second-life sector. For instance, companies in regions with robust government support in the form of financial incentives or favorable regulations might have a competitive edge over those in areas with less support. Understanding these geographic disparities could lead to more targeted and effective policy interventions.

Additionally, the impact of geographical location on a company's ability to access government financial assistance or regulatory support warrants in-depth study. This research could explore how regional policies and economic conditions influence a company's growth and sustainability strategies. By identifying the barriers and facilitators to accessing such support, stakeholders can work towards creating a more equitable and supportive business environment.

Another crucial research direction is the standardization of processes within the EV Li-ion second-life sector. Currently, the industry faces challenges due to a lack of uniform standards in recycling, repurposing, reusing, and remanufacturing processes. Standardization could significantly streamline operations, reduce costs, and improve efficiency. Research in this area could focus on developing comprehensive guidelines and best practices that can be adopted universally. This would not only ease current operational challenges but also lay a solid foundation for future business models and practices in the industry.

Standardization is also crucial for ensuring the safety, sustainability, and efficiency of the recycling and remanufacturing processes. It can facilitate better integration of these

processes into the broader circular economy, ensuring that the EV battery lifecycle is managed in an environmentally responsible and economically viable manner.

5.3.1 Addressing Supply Chain Challenges

One of the key findings from this study was the challenge of securing a consistent supply of used batteries, as indicated by 33,3% of the participated companies. This challenge poses a significant barrier to the scalability and sustainability of recycling and remanufacturing operations. Future research should therefore focus on developing strategies to overcome these supply chain constraints. This could involve exploring alternative sources of used batteries, improving collection and logistics networks, or investigating ways to incentivize battery return from end-users. Additionally, examining the potential of cross-industry partnerships could provide valuable insights into creating more robust and resilient supply chains.

5.3.2 Encouraging Technological Innovation

Technological innovation emerged as a vital component in the industry, with 63,6% of respondents highlighting the role of automated disassembly and recycling systems in improving efficiency. Future research should delve into the development and implementation of such technologies. This includes not only enhancing existing methods but also exploring emerging technologies like artificial intelligence, machine learning for process optimization (18,2%), and blockchain for supply chain transparency (18,2%). Research in this area could lead to significant advancements in the efficiency, effectiveness, and environmental impact of recycling and remanufacturing processes.

5.3.3 Enhancing Regulatory Frameworks

The study highlighted the importance of regulatory frameworks in shaping the industry, with 72,7% of companies implementing regulations on EV Li-ion battery disposal. Future research should focus on evaluating the effectiveness of these regulations and exploring ways to enhance them. This could involve assessing the impact of existing policies, identifying gaps in the current regulatory landscape, and proposing new regulations or amendments. Research in this area should also consider the global context, as harmonized international standards could significantly benefit the industry.

5.3.4 Promoting Consumer Awareness and Engagement

Finally, the study indicated a need for greater consumer awareness and engagement, with 40% of companies focusing on educating consumers about the benefits of circular economy practices. Future research should explore strategies to increase consumer

awareness and promote sustainable consumption. This could include investigating effective communication methods, analyzing consumer behavior regarding recycled and repurposed products, and identifying barriers to consumer engagement. Increasing consumer awareness not only supports market growth for recycled products but also contributes to broader environmental sustainability goals.

In summary, future research and industry practices should focus on addressing supply chain challenges, encouraging technological innovation, enhancing regulatory frameworks, and promoting consumer awareness and engagement. These areas are crucial for the continued growth and sustainability of the EV battery recycling and remanufacturing industry.

5.4 Closing Thoughts

5.4.1 The Path Forward for the EV Battery 2nd Use Sector

The EV battery recycling and remanufacturing sector stand at a crucial juncture. With the rapid growth of the EV market, the need for sustainable and efficient recycling and remanufacturing practices has never been more urgent. This study has shed light on the current state of the industry, revealing both the opportunities and challenges that lie ahead. The path forward for the sector involves not only navigating the complexities of supply chain management and technological advancements but also embracing regulatory changes and public awareness initiatives.

One of the study's key revelations is the vital role of collaboration and partnerships in driving the industry forward. As the sector evolves, it is becoming increasingly clear that no single entity can tackle the challenges alone. Collaborative efforts between manufacturers, policymakers, recycling companies, and consumers are essential for creating a sustainable circular economy for EV batteries.

5.4.2 Final Reflections on the Study’s Contributions

This research has made significant contributions to the understanding of the EV battery recycling and remanufacturing sector. By employing a mixed-methods approach, the study provided a comprehensive overview of the industry's current business models, revenue streams, and key challenges. The insights gained from this research are valuable not only for industry stakeholders but also for policymakers and researchers.

The study's findings highlight the importance of addressing high operational costs, developing robust partnerships, and embracing technological innovations. These

elements are crucial for building a resilient and economically viable industry. The research also underscores the need for stringent regulatory frameworks and consumer education to ensure the long-term sustainability of the sector.

5.4.3 A Call to Action for Continued Research and Collaboration

Considering the findings, this study underscores the importance of advancing research and collaboration within the EV battery recycling sector. Future investigations should not only aim to address the challenges identified, particularly in areas of supply chain management and technological innovation but also focus on the practical application of theoretical business models. There's a critical need to bridge the gap between theoretical frameworks and their practical implementation in the real world. This involves developing business models that are not only robust on paper but also viable and effective in the industry's operational context.

Additionally, enhancing regulatory frameworks to align with the fast-paced changes in the industry is crucial. Alongside this, increasing public awareness about the significance of battery recycling and consumer roles in a circular economy is vital. Educational initiatives and strong communication strategies can significantly influence sustainable consumption patterns.

In conclusion, the EV battery recycling sector stands on the cusp of considerable growth and change. The insights from this study lay the groundwork for further research and practical industry applications. However, unlocking the full potential of this sector demands a unified effort from all stakeholders. Ongoing research that bridges theory with practice, innovative solutions, and cooperative endeavors are pivotal for steering the industry towards a sustainable and thriving future.

SUMMARY

The thesis focused on analyzing the European EV battery recycling, repurposing, reusing, and remanufacturing industry, The main objective was to explore the current business models, their strengths, challenges, strategies and revenue streams within this sector. The study employed a mixed-methods approach, combining quantitative data analysis with qualitative insights. A questionnaire distributed to industry professionals across Europe provided the primary data source.

Summary of Results: The study revealed diverse business models with a strong focus on sustainability and partnerships.
Key findings include:
Revenue Streams: The primary revenue sources are sales of recycled or repurposed batteries and fee-based recycling services. Other significant income comes from partnerships, consulting services, and selling by-products.
Challenges: High operational costs, lack of consistent battery supply, and insufficient partnerships were highlighted as major challenges. Technological advancements, such as automated systems and advanced diagnostics tools, were identified as potential solutions.
Value Propositions: Companies differentiate themselves through proprietary technologies, industry expertise, and strategic partnerships.
Evaluation of Results
The research findings offer valuable insights into the operational dynamics of the EV battery recycling and remanufacturing sector in Europe. The study underscores the importance of sustainable business practices and the need for industry-wide collaboration.
Future Considerations: The study identifies areas for future research, including exploring strategies to overcome supply chain challenges and the impact of emerging technologies on the industry. Additionally, developing more comprehensive regulations and increasing consumer awareness are crucial for the sector's growth.

KOKKUVÕTE

Väitekirja fookuses oli Euroopa elektriautode akude taaskasutamise, ümbertöötlemise, uuesti kasutamise ja ümbertegemise tööstuse analüüs. Peamine eesmärk oli uurida praeguseid ärimudeleid, nende tugevusi, väljakutseid, strateegiaid ja tulusid selles sektoris. Uuring kasutas segameetodite lähenemist, ühendades kvantitatiivse andmeanalüüsi kvalitatiivsete ülevaadetega. Küsimustik, mis levitati tööstuse spetsialistide seas üle Euroopa, oli peamine andmeallikas.

Tulemuste kokkuvõte: Uuring paljastas mitmekesised ärimudelid, millel on tugev keskendumine jätkusuutlikkusele ja partnerlustele.

Peamised leiud hõlmavad järgmist:

Tulud: Peamised tuluallikad on taaskasutatud või ümbertöötatud akude müük ja tasupõhised taaskasutusteenused. Teised olulised sissetulekud tulevad partnerlustest, konsultatsiooniteenustest ja kõrvaltoodete müügist.

Väljakutsed: Suured tegevuskulud, akude pideva varustamise puudumine ja piisavate partnerluste puudumine toodi välja kui peamised väljakutsed. Potentsiaalseteks lahendusteks tuvastati tehnoloogilised edusammud, nagu automatiseeritud süsteemid ja täiustatud diagnostikavahendid.

Väärtuspakkumised: Ettevõtted eristavad end omanduslike tehnoloogiate, tööstusekspertiisi ja strateegiliste partnerlustega.

Tulemuste hindamine

Uuringu tulemused pakuvad väärtuslikke ülevaateid Euroopa elektriautode akude taaskasutamise ja ümbertöötamise sektori tegevusdünaamikast. Uuring rõhutab jätkusuutlike äritavade olulisust ja vajadust tööstusharuülese koostöö järele.

Tuleviku kaalutlused: Uuring tuvastab tulevikus uurimiseks valdkondi, sealhulgas strateegiad tarneahela väljakutsete ületamiseks ja uute tehnoloogiate mõju uurimiseks tööstusele. Lisaks on sektori kasvu jaoks olulised ulatuslikumad määrused ja tarbijateadlikkuse suurendamine.

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APPENDIX A: Free4LIB Resume

FREE4LIB

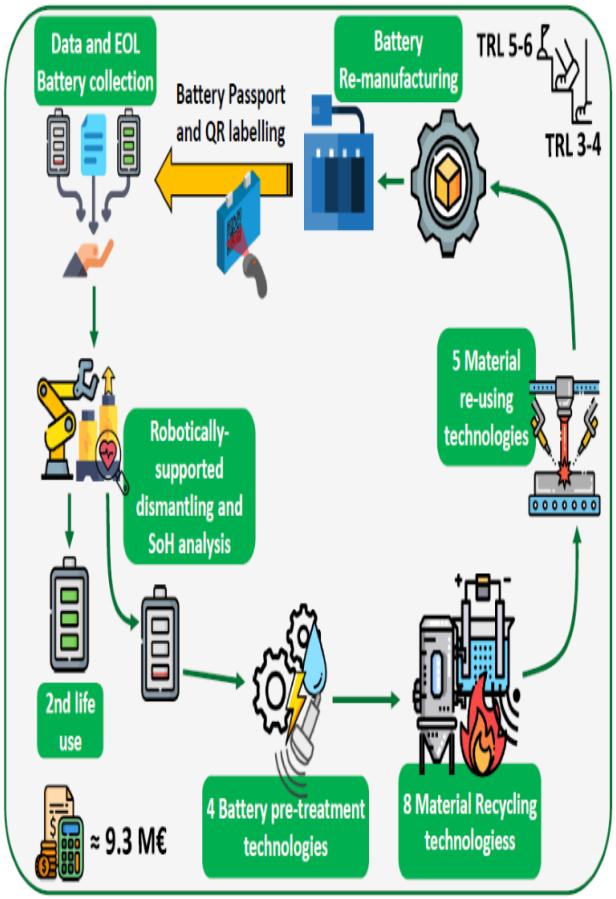
Feasible REcovery of critical raw materials through a new circular Ecosystem FOR a Li-Ion Battery cross-value chain in Europe

- Create feasible and holistic recycling processes by analysing and evaluating data from LIBs.
- Develop sustainable and efficient technological solutions for recycling different Li-battery chemistries and material re-using based on intelligent process design to optimise its scale up.
- Recover higher amount of resources from spent LIBs to use as secondary raw materials in new batteries based on a sustainable transferability model to improve vertical integration on manufacturing.
- Design for Recycling (DfR) of new Li-batteries
- Create a Battery Passport and battery recycling modelling platforms
- Research on 21 technologies covering the entire Li-ion battery value chain

Consortium of 21 partners from 7 different countries, coordinated by CARTIF:

CARTIF, CSIC, EUROBAT, Fondazione Bruno Kessler, Uni Graz, eurecat, ALIÉNOR, ITL, IREC, Fraunhofer IWKS, TORRECID, Sakarya University, ACCUREC Recycling GmbH, WATT4EVER Batteries for Life, Politecnico di Milano, erion, AVL, next move, NESSTEC, Lurederra centro tecnológico, AIMPLAS, recyclia

For more information: https://cordis.europa.eu/project/id/101069890



Funded by the European Union

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APPENDIX B: THE QUESTIONNAIRE

1. **Name** *

2. **Role** *

3. **Company** *

4. **Country** *

1. What is the main business of your company? *

Check all that apply

Check all that apply.

- [ ] Recycling
- [ ] Remanufacturing/Repurposing
- [ ] Other: _____

2. What could be the the main strengths of your business model?

Check all that apply

Check all that apply.

- [ ] Efficient and cost-effective recycling processes
- [ ] Advanced technology and equipment for battery analysis and testing
- [ ] Strong partnerships with EV manufacturers, battery manufacturers, and other industry stakeholders
- [ ] High-quality standards for recycled or remanufactured batteries
- [ ] Diverse sales channels and distribution networks
- [ ] Robust research and development capabilities
- [ ] Well-established customer base and brand reputation
- [ ] Strong focus on sustainability and circular economy principles
- [ ] Access to funding or government support for battery recycling initiatives
- [ ] Other: _____

3. What could be the the main weaknesses of your business model?

Check all that apply

Check all that apply.

- [ ] Lack of access to a consistent supply of used batteries
- [ ] High costs associated with recycling or remanufacturing processes
- [ ] Limited technological capabilities for efficient battery analysis and testing
- [ ] Insufficient partnerships with key industry stakeholders
- [ ] Inconsistent quality standards for recycled or remanufactured batteries
- [ ] Challenges in complying with regulations and environmental standards
- [ ] Limited research and development capabilities
- [ ] Limited brand recognition or customer awareness
- [ ] Lack of funding or government support for battery recycling initiatives
- [ ] Other: _____

4. To what extent has your company formed partnerships with other industries (e.g. automotive, energy, electronics) to improve your business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing? *

Check all that apply

Check all that apply.

- [ ] We have established extensive partnerships with various industries to enhance our business model.
- [ ] We have formed some partnerships with other industries to improve our business model, but there is room for further collaboration.
- [ ] We have limited partnerships with other industries, and it has had a minimal impact on our business model.
- [ ] We have not actively pursued partnerships with other industries for our business model.
- [ ] Other: _____

5. What challenges does your company face in its current business model for recycling, repurposing, reusing, and remanufacturing EV Li-ion batteries? *

Check all that apply

Check all that apply.

- [ ] Lack of consistent and reliable supply of battery packs
- [ ] High costs associated with recycling, repurposing, reusing, and remanufacturing processes
- [ ] Limited technological capabilities for efficient and effective battery pack handling
- [ ] Difficulties in meeting quality standards and ensuring safety and performance of recycled or remanufactured battery packs
- [ ] Lack of awareness and demand for recycled or repurposed battery packs in the market
- [ ] Regulatory and compliance challenges related to environmental and waste management regulations
- [ ] Limited access to funding or investment for expanding and improving operations
- [ ] Lack of skilled workforce with expertise in EV Li-ion battery pack recycling and remanufacturing
- [ ] Competition from other companies in the same industry
- [ ] Other: _____

6. Do battery pack manufacturers take this into consideration when designing battery packs?

Mark only one oval.

- ◯ Battery pack manufacturers do consider recyclability and repurposability when designing battery packs.
- ◯ Battery pack manufacturers sometimes consider recyclability and repurposability when designing battery packs.
- ◯ Battery pack manufacturers rarely consider recyclability and repurposability when designing battery packs.
- ◯ Other: _____

7. What specific regulations or policies does your company follow to maintain an economically sustainable business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing?

Check all that apply

Check all that apply.

- ☐ Implementing stricter regulations on the disposal of EV Li-ion batteries to encourage recycling and proper handling.
- ☐ Providing financial incentives or subsidies for companies engaged in EV Li-ion battery pack recycling, repurposing, reusing, and remanufacturing.
- ☐ Establishing standardized guidelines and procedures for the safe and efficient handling of EV Li-ion batteries throughout their lifecycle.
- ☐ Encouraging research and development in battery recycling technologies to improve efficiency and reduce environmental impact.
- ☐ Introducing extended producer responsibility (EPR) programs that require manufacturers to take responsibility for the collection and recycling of their used battery packs.
- ☐ I don't believe specific regulations or policies are necessary.
- ☐ Other: _____

8. What strategies does your company employ to incorporate principles of the circular economy in its operations

Check all that apply

Check all that apply.

- ☐ Implementing efficient resource management and waste reduction practices
- ☐ Promoting repair, refurbishment, and reuse of products
- ☐ Facilitating product take-back and recycling programs
- ☐ Collaborating with suppliers to promote sustainable sourcing practices
- ☐ Exploring innovative business models such as leasing or sharing economy models
- ☐ Educating consumers about the benefits of circular economy and sustainable consumption
- ☐ Implementing reverse logistics systems for product returns and recovery
- ☐ Other: _____

9. In your business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing, how do you distribute your value proposition to different customer segments?

Check all that apply

Check all that apply.

- [ ] Direct sales to EV manufacturers and other companies in the EV supply chain.
- [ ] Partnerships with retail or distribution channels for selling to consumers or end-users
- [ ] Collaborations with specialized service providers or industry intermediaries
- [ ] Customized distribution strategies based on the specific needs of each customer segment
- [ ] Combination of multiple distribution channels to reach a broader customer base
- [ ] Other: _____

10. Are there any emerging technologies or innovations that you think could significantly improve the efficiency or effectiveness of your company's business model for EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing?

Check all that apply

Check all that apply.

- [ ] Advanced battery sorting and separation technologies
- [ ] Automated disassembly and recycling systems
- [ ] Enhanced battery testing and evaluation techniques
- [ ] Advanced battery diagnostics and refurbishment tools
- [ ] Novel recycling methods (e.g., hydrometallurgical, pyrometallurgical)
- [ ] Battery-to-battery recycling processes
- [ ] Energy storage systems using recycled battery packs
- [ ] Artificial intelligence and machine learning for process optimization
- [ ] Blockchain technology for traceability and transparency in the supply chain
- [ ] Other: _____

11.What value propositions differentiate your company from others in the EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing industry?

Check all that apply

Check all that apply.

- [ ] Cutting-edge proprietary technologies or innovative processes that enhance the efficiency, effectiveness, or cost-effectiveness of battery pack recycling/remanufacturing.
- [ ] Expertise and experience in the industry, providing in-depth knowledge of battery pack characteristics, performance, and specific requirements for successful recycling/remanufacturing.
- [ ] Broad network of strategic partnerships with key stakeholders in the EV industry, such as automakers, battery manufacturers, or other recycling and remanufacturing companies, enabling collaboration and access to additional resources.
- [ ] Proven track record and successful case studies showcasing the company's ability to deliver high-quality, reliable, and cost-effective recycled or repurposed battery packs to satisfied customers.
- [ ] Competitive pricing and cost structures that provide attractive financial benefits for customers seeking cost-effective and environmentally responsible solutions for their used battery packs.
- [ ] Other: _____

12. What are the main sources of revenue for your business model in the EV Li-ion batteries recycling, repurposing, reusing, and remanufacturing industry? How does your company generate income from its activities?"

Check all that apply

Check all that apply.

- [ ] Fee-based revenue from recycling or remanufacturing services
- [ ] Sales revenue from selling recycled or repurposed battery packs
- [ ] Revenue from partnerships and collaborations with other companies
- [ ] Revenue from licensing or technology transfer agreements
- [ ] Revenue from providing consulting or advisory services in the industry
- [ ] Revenue from value-added services such as battery testing or certification
- [ ] Implementing comprehensive safety protocols and risk management strategies
- [ ] Revenue from selling by-products or secondary materials derived from the recycling process
- [ ] Other: _____

APPENDIX C: SCOPUS AND GOOGLE SCHOLAR

1.1 APPENDIX C.1

Table C.1 Scopus Search Results

Authors	Year	Title
Fallah N.; Fitzpatrick C.	2023	Is shifting from Li-ion NMC to LFP in EVs beneficial for second-life storages in electricity markets?
Börner M.F.; Frieges M.H.; Späth B.; Spütz K.; Heimes H.H.; Sauer D.U.; Li W.	2022	Challenges of second-life concepts for retired electric vehicle batteries
Olsson L.; Fallahi S.; Schnurr M.; Diener D.; van Loon P.	2018	Circular business models for extended ev battery life
Schulz-Mönninghoff M.; Bey N.; Nørregaard P.U.; Niero M.	2021	Integration of energy flow modelling in life cycle assessment of electric vehicle battery repurposing: Evaluation of multi-use cases and comparison of circular business models
Alamerew Y.A.; Brissaud D.	2020	Modelling reverse supply chain through system dynamics for realizing the transition towards the circular economy: A case study on electric vehicle batteries
Baars J.; Domenech T.; Bleischwitz R.; Melin H.E.; Heidrich O.	2021	Circular economy strategies for electric vehicle batteries reduce reliance on raw materials
Islam M.T.; Iyer-Raniga U.; Trewick S.	2022	Recycling Perspectives of Circular Business Models: A Review
Kastanaki E.; Giannis A.	2023	Dynamic estimation of end-of-life electric vehicle batteries in the EU-27 considering reuse, remanufacturing and recycling options
Vu F.; Rahic M.; Chirumalla K.	2020	Exploring Second Life Applications for Electric Vehicle Batteries
Ramirez-Meyers K.; Rawn B.; Whitacre J.F.	2023	A statistical assessment of the state-of-health of LiFePO4 cells harvested from a hybrid-electric vehicle battery pack
Franco M.A.; Groesser S.N.	2021	A systematic literature review of the solar photovoltaic value chain for a circular economy
Nurdiawati A.; Agrawal T.K.	2022	Creating a circular EV battery value chain: End-of-life strategies and future perspective
Silvestri L.; De Santis M.; Bella G.	2022	A Preliminary Techno-Economic and Environmental Performance Analysis of Using Second-Life EV Batteries in an Industrial Application
Martin M.; Heiska M.; Björklund A.	2021	Environmental assessment of a product-service system for renting electric-powered tools
Agrawal T.K.; Angelis J.; Thakur J.R.; Wiktorsson M.; Kalaiarasan R.	2021	Enabling circularity of electric vehicle batteries-the need for appropriate traceability
Wrålsen B.; O'Born R.	2023	Use of life cycle assessment to evaluate circular economy business models in the case of Li-ion battery remanufacturing
Schulz-Mönninghoff M.; Evans S.	2023	Key tasks for ensuring economic viability of circular projects: Learnings from a real-world project on repurposing electric vehicle batteries
Shafinejad P.; Georgopoulos K.; Bolech M.; Copani G.	2023	A New Business Model for the Circular Economy of Electric Vehicles
Apalkova V.; Tsyganov S.; Chernytska T.;	2021	Evaluating the economic and ecological effects of investment projects: A new model and its application to smartphone manufacturing in Europe

Meshko N.; Tsyganova N.		
Chirumalla K.; Kulkov I.; Vu F.; Rahic M.	2023	Second life use of Li-ion batteries in the heavy-duty vehicle industry: Feasibilities of remanufacturing, repurposing, and reusing approaches
Rajaeifar M.A.; Ghadimi P.; Raugei M.; Wu Y.; Heidrich O.	2022	Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective
Albertsen L.; Richter J.L.; Peck P.; Dalhammar C.; Plepys A.	2021	Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU
Lima M.C.C.; Pontes L.P.; Vasconcelos A.S.M.; de Araujo Silva Junior W.; Wu K.	2022	Economic Aspects for Recycling of Used Lithium-Ion Batteries from Electric Vehicles
Kautz E.; Bozkurt Ö.F.; Emmerich P.; Baumann M.; Weil M.	2021	Potentials and challenges of a circular economy. A systematic review for the use case of lithium-ion batteries

1.2 APPENDIX C.2

Table C.2 Google Scholar Search Results

Authors	Year	Title
Lih, Wen-Chen; Yen, Jieh-Hwang; Shieh, Fa-Hwa; Liao, Yu-Min;	2012	Second use of retired lithium-ion battery packs from electric vehicles: technological challenges, cost analysis and optimal business model
Kotak, Yash; Marchante Fernández, Carlos; Canals Casals, Lluc; Kotak, Bhavya Satishbhai; Koch, Daniel; Geisbauer, Christian; Trilla, Lluís; Gómez-Núñez, Alberto; Schweiger, Hans-Georg;	2021	End of electric vehicle batteries: Reuse vs. recycle
Leal, VM; Ribeiro, JS; Coelho, ELD; Freitas, MBJG;	2023	Recycling of spent lithium-ion batteries as a sustainable solution to obtain raw materials for different applications
Ngô, ChristianVE; Priem, Thierry; Martinet, Sébastien;	2022	Li-ion Battery Recycling
Pražanová, Anna; Knap, Vaclav; Stroe, Daniel-Ioan;	2022	Literature review, recycling of lithium-ion batteries from electric vehicles, part II: Environmental and economic perspective
Sun, Bingxiang; Su, Xiaojia; Wang, Dan; Zhang, Lei; Liu, Yingqi; Yang, Yang; Liang, Hui; Gong, Minming; Zhang, Weige; Jiang, Jiuchun;	2020	Economic analysis of lithium-ion batteries recycled from electric vehicles for secondary use in power load peak shaving in China
Reinhardt, Robert;	2019	Sustainable business model perspectives for the electric vehicle industry: the case of battery second use
Meihan, Yu;		Life-cycle environmental and economic assessment of electric vehicle lithium-ion batteries using different recycling methods in a closed loop supply chain

Díaz Caballo, Marc;	2021	Viability of Electronic vehicle li-ion batteries for stationary storage applications in the EU by 2030
Idjis, Hakim; Attias, Danielle; Bocquet, Jean Claude; Richet, Sophie;	2013	Designing a sustainable recycling network for batteries from electric vehicles. Development and optimization of scenarios
Jiao, Na; Evans, Steve;	2016	Business models for sustainability: the case of second-life electric vehicle batteries
Bergh, William;	2020	Mapping the European reverse logistics of electric vehicle batteries
Milani, Sadaf; Besharat, Zahra;	2022	Circular Business Models for the Second Life Cycle of Electric Vehicle Batteries: Opportunities and Barriers
Walz, Phillip Niklas;	2021	A circular economy in electric vehicle batteries: a european perspective
Hill, Nikolas; Clarke, Dan; Blair, Laura; Menadue, Hetty;	2019	Circular economy perspectives for the management of batteries used in electric vehicles
Rallo, H; Casals, L Canals; De La Torre, David; Reinhardt, Robert; Marchante, Carlos; Amante, B;	2020	Lithium-ion battery 2nd life used as a stationary energy storage system: Ageing and economic analysis in two real cases
Alcevska, Elma;	2020	Business model for Take-back-The case of High Voltage Lithium-ion batteries in the European market
Kautz, Emilia; Bozkurt, Ömer F; Emmerich, Philip; Baumann, Manuel; Weil, Marcel;	2021	Potentials and challenges of a circular economy. A systematic review for the use case of lithium-ion batteries
Al-Alawi, Mohammed Khalifa; Cugley, James; Hassanin, Hany;	2022	Techno-economic feasibility of retired electric-vehicle batteries repurpose/reuse in second-life applications: A systematic review
Heath, Garvin A; Ravikumar, Dwarakanath; Hansen, Brianna; Kupets, Elaine;	2022	A critical review of the circular economy for lithium-ion batteries and photovoltaic modules–status, challenges, and opportunities
van Oyen, Coen Smits; Blankesteijn, ML; van der Sijde, PC;	2021	Towards a more circular business model: extended EV battery lifetime