Evaluating Reverse Logistics and Second Life Applications of End-of-Life Electric Vehicle Batteries in Kenya

An Exploratory Single Case Study at Roam Electric

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MASTER THESIS

Evaluating Reverse Logistics and Second Life Applications of End-of-Life Electric Vehicle Batteries in Kenya

An Exploratory Single Case Study at Roam Electric

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Abstract

The rapid growth of the global electric vehicle (EV) market has led to an increased focus on the lifecycle management of electric vehicle batteries (EVBs), particularly concerning their end-of-life (EoL) handling. The thesis explores and evaluates the implementation of reverse logistics (RL) setups for EoL EVBs of electric motorcycles in Kenya, a market that is observing an increasing EV sector but lacks a structured approach to battery EoL management. The study is focused on Roam Electric, a Nairobi-based electric mobility startup, and utilises an exploratory single case study methodology to examine the practical and theoretical aspects of RL in an emerging market context.

The research identifies key barriers and enablers within the Kenyan market, including economic, regulatory, and infrastructural factors influencing the viability of RL and EoL handling for EVBs. Through a comprehensive analysis, combining empirical data and theoretical insights, the study proposes actionable strategies that can enable efficient and sustainable EoL handling of EVBs. These strategies focus on leveraging circular economy principles to extend the life cycle of EVBs through repurposing and recycling, thus mitigating environmental impact and enhancing economic value.

The findings suggest that while there are significant challenges, there are also opportunities in Kenya for establishing a robust RL setup. These include the potential for creating new business models around battery second life applications, such as battery energy storage systems (BESS). Through evaluating the viability of producing second life BESS, the thesis concludes it to be a financially feasible opportunity under the right circumstances, also contributing to environmental sustainability. The thesis contributes to the broader discussion on supply chain management, circular economy, and sustainable practices in the EV industry, providing a way for similar markets looking to integrate EoL strategies for EVBs.

Key words: Electric Vehicle Batteries, End-of-Life, Reverse Logistics, Second Life Application, Battery Energy Storage System, Circular Economy, Kenya

Contribution: This thesis has been a complete elaboration between the two authors. Each author has been involved in every part of the process and contributed equally.

Sammanfattning

Den snabba tillväxten av den globala elfordonsmarknaden har lett till ett ökat fokus på livscykelhantering av elfordonsbatterier, särskilt när det gäller hanteringen av uttjänta batterier. Den här uppsatsen utforskar och utvärderar implementeringen av returlogistik för uttjänta batterier till eldrivna motorcyklar i Kenya, en marknad där elfordonssektorn ökar men där det saknas ett strukturerat tillvägagångssätt för hantering av uttjänta batterier. Studien fokuserar på Roam Electric, ett startup inom elektrisk mobilitet baserat i Nairobi, och använder en metodik för fallstudier för att undersöka de praktiska och teoretiska aspekterna av returlogistik på en framväxande marknad.

Uppsatsen identifierar viktiga hinder och möjliggörare på den kenyanska marknaden, inklusive ekonomiska, regulatoriska och infrastrukturella faktorer som påverkar lönsamheten för returlogistik av elfordonsbatterier. Genom en omfattande analys som kombinerar empirisk data och teoretiska insikter, föreslår studien konkreta strategier för att möjliggöra en effektiv och hållbar hantering av uttjänta elfordonsbatterier. Strategierna betonar användningen av principer för cirkulär ekonomi för att förlänga batteriets livslängd genom återanvändning och återvinning, vilket både minskar miljöpåverkan och ökar det ekonomiska värdet.

Resultaten tyder på att även om det finns betydande utmaningar, finns det också möjligheter i Kenya att etablera robusta strategier för returlogistik. Bland dessa möjligheter finns potentialen att skapa nya affärsmodeller kring andra batteritillämpningar, såsom energilagringssystem. Genom att utvärdera lönsamheten av att producera energilagringssystem med uttjänta batterier, dras slutsatsen att det är en ekonomiskt genomförbar möjlighet under rätt omständigheter, som också bidrar till miljömässig hållbarhet. Uppsatsen bidrar till den bredare diskussionen om supply chain management, cirkulär ekonomi och hållbara metoder inom elfordonssindustrin, och erbjuder en vägledning för liknande marknader som vill integrera strategier för uttjänta elfordonsbatterier.

Nyckelord: Elfordonsbatterier, Uttjänta batterier, Returlogistik, Second-life-applikation, Batterilager, Cirkulär ekonomi, Kenya

Bidrag: Detta examensarbete är resultatet av ett samarbete mellan författarna. Båda författarna har varit med i alla delar i processen och bidragit till lika delar.

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Abbreviations

BESS – Battery Energy Storage System
BEV – Battery Electric Vehicle
BMS – Battery Management System
CE – Circular Economy
CSR – Corporate Social Responsibility
EoL – End-of-life
EPR – Extended Producer Responsibility
EV – Electric Vehicle
EVB – Electric Vehicle Battery
GHG – Greenhouse Gas
kWh – Kilowatt hour
LiB – Lithium-Ion Battery
OECD – Organization for Economic Co-operation and Development
RL – Reverse Logistics
SC – Supply Chain
SCM – Supply Chain Management
SCND – Supply Chain Network Design
SoC – State-of-Charge
SoH – State-of-Health
WEEE – Waste of Electrical and Electronic Equipment

1. Introduction

The introduction chapter presents the thesis background, describes the problem to be analysed, and introduces the purpose of the study. Thereafter, the research question and objectives are formulated. Finally, the focus and delimitations as well as an overview of the thesis structure are presented.

1.1 Background

In the *Sixth Assessment Report,* IPCC (2023, pp. 42-43) declares the emissions of greenhouse gases caused by human activities as the main contributor to global warming. A global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020 is already causing weather and climate extremes across the globe, impacting everything from food and water security to nature. To reduce the impact of the ongoing climate crisis, changes to becoming more environmentally sustainable are necessary across industries (World Economic Forum, 2020).

In 2019, the transportation sector contributed to approximately 25% of the global greenhouse gas emissions, which is driven by the sector's high reliance on fossil fuels (National Business Initiative, 2022, p. 22). Furthermore, road transport accounts for 80% of the sector's emissions, indicating a necessary shift towards more environmentally sustainable alternatives. Recognising this needed shift, electric vehicles (EVs) have become a significant player in reducing carbon emissions from road transport (Statista, 2024a). The EV sector is witnessing an increasing global demand, forecasted to grow at an annual rate of 9.82% from 2024 to 2028. If the current trend continues, CO_2 emissions from cars could, by 2030, get on a pathway aligned with the Net Zero Emissions by 2050 Scenario (International Energy Agency, 2023). However, the global growth of the EV market is currently predominantly limited to China, the U.S., and Europe, accounting for about 95% of global sales.

Despite only contributing to 2-3% of the global emissions, Africa is disproportionately the most vulnerable region to climate change (African Development Bank, 2024). The UN projects Africa's population to grow from 1.4 billion today to 3.9 billion by the end of the century, calling for urgent adaptation as population growth and climate change threaten significant habitat loss (Nater, 2022). Almost all African countries have committed to reducing greenhouse gas emissions and building resilience (African Development Bank, 2024). While being an urgent threat, climate change also presents opportunities for Africa to leverage its resources to reach climate goals and create significant market opportunities for both the private sector and institutional investors.

The expansion of numerous African cities, for example, brings a heightened focus on sustainable transport to enhance livability and productivity (Njogu, 2023). Nairobi, Kenya, is one of these cities, with the country having a target to expand the percentage of yearly imported EVs to 5% by 2025 (Ministry of Energy, 2020). This aligns with their commitment to the COP26 declaration – aiming to accelerate the transition to 100% zero-emission cars and vans. Despite being in its early stages, Kenya's EV sector is promising, with a significant number of vehicles out on the roads, primarily two-wheelers (Njogu, 2023). Moreover, a recent study by Conzade et al. (2022)

highlights a rapid increase in demand and predicts that Kenya will undergo a faster transition than most countries in the region. The study anticipates EVs to account for 60-75% of all two-wheeler sales in the country by the year 2040. Furthermore, the study estimates that more than 20 startups were operating within the Sub-Saharan EV market by the end of 2021. One of these startups is the case company of the thesis, Roam Electric, an electric motorcycle manufacturer operating in Nairobi.

The rising demand for EVs is driving an exponential growth in the production of essential lithium-ion batteries (LiBs). Although batteries play a crucial role in addressing climate change, true progress cannot be realised without a fundamental shift in the sourcing of materials, production and utilisation of the technology (World Economic Forum, 2019). The production of LiBs requires a considerable amount of energy which is associated with CO_2 emissions. Moreover, the increased demand for raw materials, especially nickel, lithium and cobalt, comes with social, environmental and integrity concerns. Therefore, to ensure a sustainable value chain for batteries and EVs, implementation of end-of-life (EoL) handling through various circular economy (CE) mechanisms is necessary.

Once the battery reaches its EoL, a stage when it can no longer be used for EVs, the battery still has 70-80% of its total capacity left (Illa Font et al., 2023; Sun et al., 2018; Sheikh et al., 2022; Volvo Energy, 2023). Ensuring circularity and giving batteries a second life, through making sure they are used to their full potential before being recycled, is therefore crucial for reducing the environmental impact of the industry. A prerequisite of enabling circularity and closing the loop of EVBs is implementing reverse logistics (RL) of the EoL batteries.

1.2 Problem Formulation

With the expected increase in EV and EVB demand in Kenya, followed by the enhanced need of EoL battery handling, implementing RL is essential. As the EV market in Kenya is emerging, there is currently no widely adopted system for RL of EoL EVBs. This is a challenge for EV manufacturers working on minimising the carbon footprint of the transportation sector, as remanufacturing, repurposing and recycling, all of which are enabled by RL, are essential factors in this transformation. Eminent companies within EoL battery handling are, as of 2019, limited to the Chinese, U.S., and European market (World Economic Forum, 2019) with prerequisites varying significantly from the Kenyan market in terms of regulations, logistic opportunities, active actors and recycling systems. Given this background, it is both of need and interest to investigate potential opportunities of implementing RL, including design, incentives and economic feasibility, for an EV manufacturer operating in the Kenyan market.

1.3 Purpose

The purpose of this thesis is to, from a reverse logistics point of view, develop and evaluate actionable strategies enabling an efficient and sustainable end-of-life handling of electric vehicle batteries in Kenya.

1.4 Research Question

Originating from the purpose of the thesis, the main research question concerns the potential RL setups. The question is formulated as follows:

RQ: How can a Kenyan electric vehicle producing company benefit from implementing a reverse logistics setup and end-of-life handling strategy for electric vehicle batteries?

To address the research question, a comprehensive examination of an EV producing company's operations and supply chain (SC), focusing on the existing prerequisites that support the implementation of a reverse logistic setup, is essential. An initial SC mapping of the case company, Roam Electric, will be used as a base for investigating reversed setups, formulating the first research objective:

RO1: Map the current and planned logistical flows of the Roam Electric motorcycle batteries.

To complement RO1 and to be able to provide a valid solution to the RQ, an investigation of needed resources and limiting factors of RL for EoL EVBs is essential. This includes understanding the regulatory and logistic limitations as well as identifying potential solutions for EoL handling. As the global EoL EVB market is emerging, and Kenya is not in the forefront, the European context is also investigated to be used as a reference point. This leads to following research objective:

RO2: Map the barriers and enablers of implementing a reverse logistic setup of end-of-life electric vehicle batteries.

To propose a practical and implementable RL strategy, different solutions must be explored. Building on the insights from RO1 and RO2, a solution space will be created, and potential solutions will be compared, leading to the final research objective:

RO3: Suggest viable, environmentally and economically sustainable, reverse logistic setups for the Kenyan market.

1.5 Focus and Delimitations

The research is limited to LiBs of battery electric vehicles (BEVs), further referred to as EVs. Furthermore, the study is geographically limited to Kenya and battery manufacturers are therefore not part of the scope. As current regulations and practices regarding EoL EVB handling are further developed in other parts of the world, especially China, the U.S., and Europe, international perspectives will be integrated into the theoretical framework. However, although China and the U.S. are significant players in the EV market, Europe is used as a reference market throughout the thesis. This decision stems from practical advantages since Europe is a familiar market for both the authors and the case company having Swedish founders. The familiarity provides a basic understanding and easier access to relevant stakeholders. The time limitation of 20 weeks also affects the extent of the data collection and other research aspects.

1.6 Structure of Thesis

The thesis is organised into seven different chapters: 1. Introduction, 2. Theoretical Background, 3. Methodology, 4. Empirics, 5. Analysis, 6. Evaluation and 7. Conclusion. The chapters are structured in alignment with the problem-solving approach of the thesis. Initially, the background and problem are formulated, followed by a presentation of the theoretical framework providing context to the overall scope. Following this, an explanation of how the developed framework, along with the case study, will effectively address the research question is provided. After the methodology is presented, the empirics presents the collected data, which, alongside the insights from the literature review, form the foundation for addressing the research question. The following analysis involves creating strategies for implementing reverse logistic of EVBs in Kenya and leads to a proposed RL setup and varying business cases for second life applications, which are then evaluated and compared. Finally, the conclusion chapter summarises the findings and answers the research question and research objectives. *Figure 1.1* illustrates the overall structure of the thesis and the outputs of each chapter.

Chapter	Focus of Thesis		Output
1	Introduction	→	Research question and objectives
2	Theoretical Background	→	Theoretical framework
3	Methodology	→	Problem solving approach and design of the thesis
4	Empirics	→	Findings from the case study
5	Analysis	→	Propsosed logistical setup and potential business cases
6	Evaluation	→	Evaluation of the reverse logistic setup and the potential business cases
7	Conclusion	→	Adressing the research objectives and answering the research question

Figure 1.1. An illustration of the thesis structure, including the main output of every chapter.

2. Theoretical Background

To build a fundamental understanding of the scope of the thesis and achieve relevance, the theoretical background is divided into three main sub-chapters, as illustrated in Figure 2.1. The chapters cover electric vehicle batteries, supply chain theory, and the Kenyan market conditions. As answering the research question requires an initial understanding of EVBs and current practices within the industry, these areas constitute the first sub-chapter. Thereafter, to understand the enablers and barriers of implementing RL, relevant SC theories are introduced. To contextualise the theoretical background of EVB and SC theory within Kenya, the working environment of the case company, a theoretical overview of the market is introduced in the final sub-chapter. The insights gained from the sub-chapters are combined in the analysis phase, thereby contributing to academia through bridging the gap between these fields.

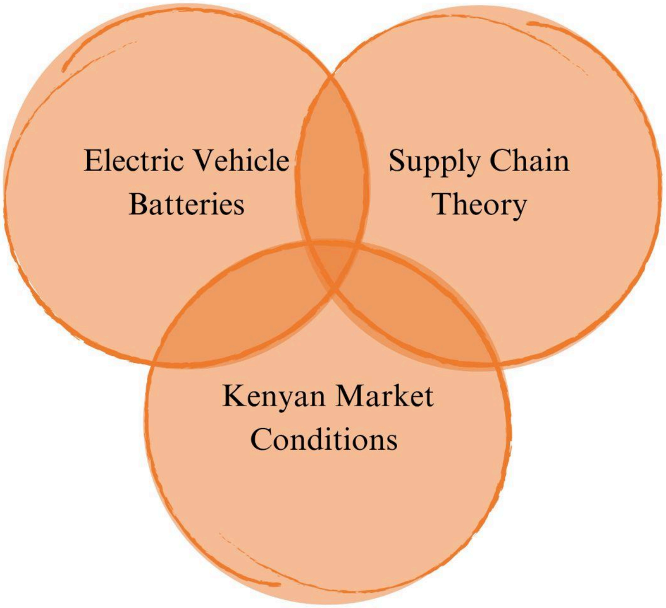

Figure 2.1. Visualisation of the theoretical framework supporting the thesis.

2.1 Electric Vehicle Batteries

This section explores the attributes and characteristics of EVBs, and offers an overview of the EVB life cycle, detailing its various phases. Additionally, the section introduces regulations affecting the EoL handling of the batteries.

2.1.1 Life Cycle

Studying several EV and EVB process flows, five main stages describing the EVB life cycle are identified (Yang, Huang and Lin, 2022; Li, Xia and Guo, 2022; Casals, Amante García and Canal, 2019). These stages are summarised as raw material extraction, EVB manufacturing, EV manufacturing, EV use and recycling, all presented in *Figure 2.2*. Additionally, the figure includes stages for repairing as well as the second life cycle. Given that the thesis focuses on reverse logistics and EoL handling, the potential second life of the EVBs is described more in detail whereas the first life cycle is only briefly described.

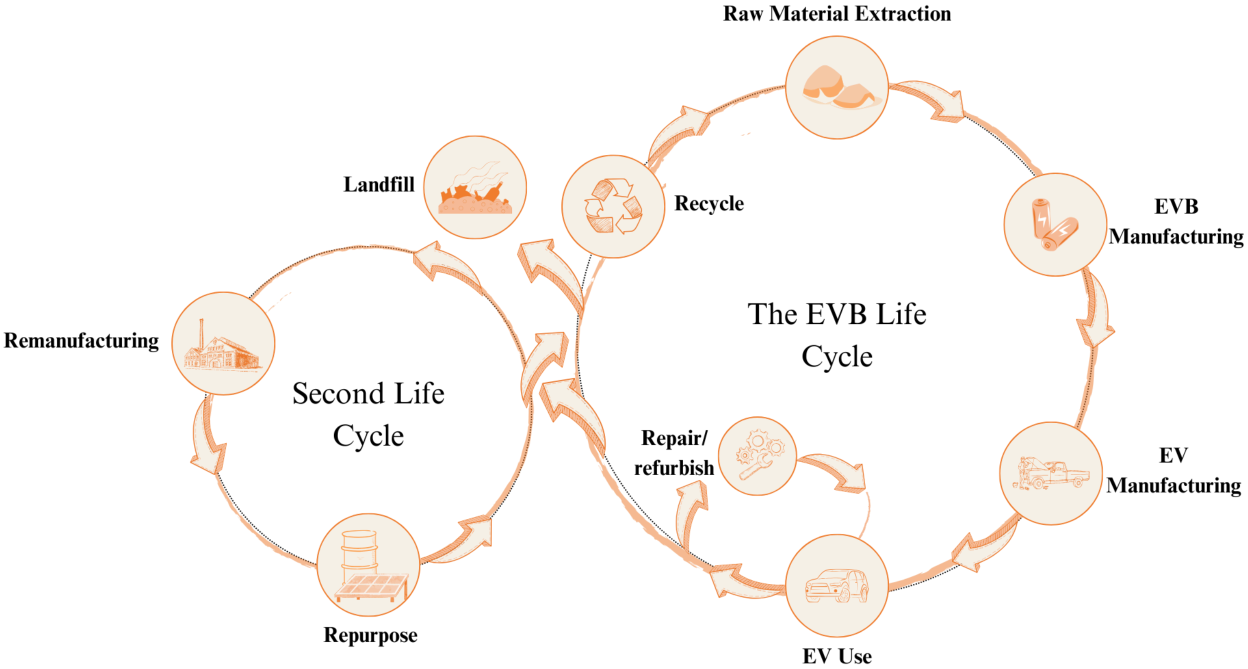

Figure 2.2. EVB life cycle (Source: Own illustration based on Yang, Huang and Lin, 2022; Li, Xia and Guo, 2022; Casals, Amante García and Canal, 2019).

First Life Cycle

Initially, the raw materials must be procured, requiring mining of raw material. Though new types of EVBs are being introduced to the market, the most commonly used one is the LiB (Evenergi, 2021b). LiBs consist of several scarce metals like lithium, cobalt, manganese, aluminium, and nickel, making this step critical for the EVB production (Nurdiawati and Agrawal, 2022; Maisel et at., 2023). Furthermore, there is also a high supply risk concerning the SC of the raw materials, due to the supply being limited to certain geographical areas. The mining of the raw materials is also associated with both social and environmental issues (Nurdiawati and Agrawal, 2022), which, together with the scarcity of the raw materials, emphasises the importance of EVB circularity (Fallah and Fitzpatrick, 2022).

Due to the high interest in the globally booming EVB market, a lot of research and development is taking place in regards to the second step of the EVB life cycle, EVB manufacturing, meaning that there are few industry-wide standards. Depending on the manufacturer, production date and purpose, the battery cells can have very varying characteristics (Nur Halima, Rahardian and Budiman, 2019; Yang, Huang and Lin, 2022). Varying, for instance, the dimensions or chemistries of the cells give different properties, yielding both advantages and disadvantages. These EVB cells are normally cylindrical, prismatic or pouch type (Nur Halima, Rahardian and Budiman, 2019; Zwicker et al., 2020). As shown in *Figure 2.3*, the battery pack of an EV consists of a number of modules, which in turn consist of a number of cells.

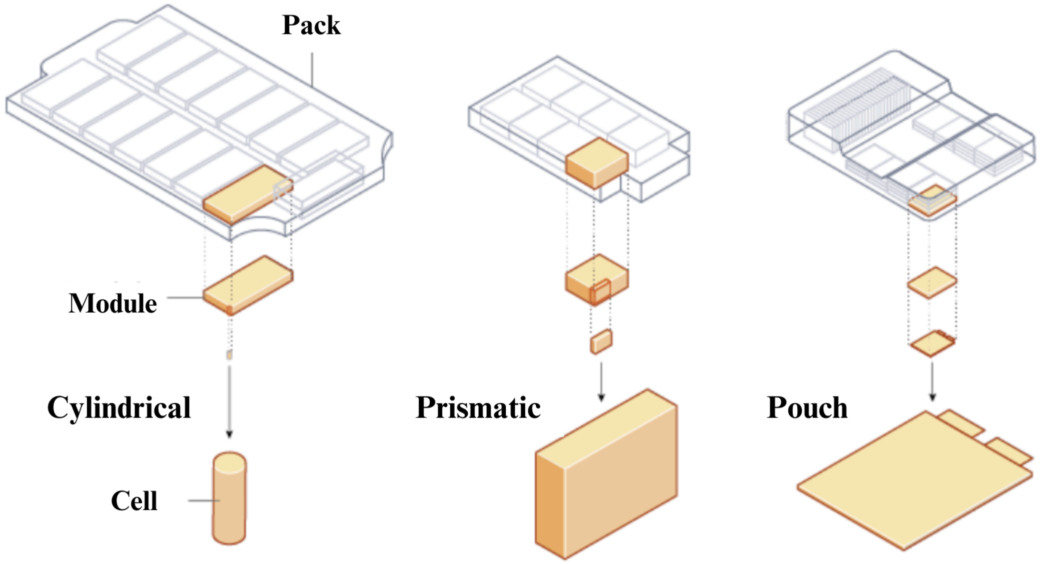

Figure 2.3. EVB pack build ups with different types of cells. (Source: Own design modified from Evenergi, 2021a)

The LiB cell consists of anode and cathode active materials that are physically separated but electrically connected using electrolyte (Harowitz and Coffin, 2018). Graphite is the most commonly used anode, whereas manipulating the cathode design at material level is essential in reaching environmental, social and economical sustainability of the LiB production (Yang, Huang and Lin, 2022). Factors to consider when evaluating cathode materials is, for instance, the electrochemical performance, in terms of energy density and life cycle et cetera, raw material abundance, cost, and greenhouse gas (GHG) emissions during both mining and production. In 2019, NMC (Nickel Manganese and Cobalt) and NCA (Nickel Cobalt and Aluminium Oxides) – popular because of their high energy density – dominated the LiB market for EVs and accounted for more than 80% of the cathode material used in new light duty vehicles. Between 2019 and 2021, however, the market share of LFP (Lithium Iron Phosphate), with its high safety, low cost and fast charging capability, grew from around 10-24% across all EV cathodes. As of 2021, China accounted for 79% of the total LiB production (Statista, 2021). However, until 2025 European countries are expected to increase their production capacities, with Germany, in the lead, being expected to account for 11% of the global production. While production is increasing, research indicates that battery prices will fall, due to falling costs of key raw materials like lithium, nickel, and cobalt (Goldman Sachs, 2023). According to predictions made by Goldman Sachs (2023), battery prices will drop to around 100 USD per kilowatt hour (kWh) by 2025, with an average annual decrease of 11% in battery pack prices from 2023 to 2030.

During the third identified step of the EVB life cycle, the battery is mounted onto the EV. There is no standard of how many cells a module consists of or, in turn, how many modules a pack consists of (Zwicker et al. 2020). Furthermore, there is no standard of how neither the cells nor the modules are connected, giving the EV manufacturers the opportunity to design for desired performance. Before going into the user phase, the EVB is tested to make sure that it reaches the requirements. Once the EV is in use, LiBs used in electric cars tend to have an average lifespan of 8-10 years (Melin, 2019), which varies depending on how the EVBs are handled. Battery degradation is divided into calendar and cycle ageing, referring to ageing when the battery is at rest, and in use or during charge respectively (Edge et al., 2021). From a user's point of view, temperature, state-of-charge (SoC) and load profile, are the three main stress factors influencing the degradation of the battery, with temperature being the most prominent. There are studies that explore new methods for cell monitoring via the Battery Management System (BMS), focusing on limiting the need for extra tests and measurements on batteries once they are removed from the EV (Lawder et al., 2014). These studies also aim to improve the understanding of battery usage patterns, which can help in making informed decisions about extending the life cycle.

When the EVB has fulfilled its intended function and its remaining capacity is deemed insufficient for use in vehicles it reaches the end of its *first* life cycle (Illa Font et al., 2023), referred to as EoL in this thesis. State-of-health (SoH) is defined as the ratio between the current capacity of a battery and its initial, original capacity (Casals, Amante García and Canal, 2019). An EVB is considered EoL when reaching a SoH of which it cannot fulfil the purpose of its application anymore, and the general recommendation from most EV manufacturers is to replace the batteries once the capacity is reduced to approximately 70-80% of the original capacity (Casals, Amante García and Canal, 2019; Illa Font et.al, 2023). According to interviews conducted by Prevolnik and Ziemba (2019), 50-60% of batteries entering return flows today do so because of damage, during production or accidents, and not through reaching EoL after capacity loss. On the other hand, the interviewees predict that this is expected to change, with a future estimation of 98% of returning batteries being in good condition.

Second Life Cycle

As EVBs reach their EoL, recycling becomes a viable option. However, there is a growing interest in exploring second life applications for these batteries in both industry and academia, due to the rising sales of EVs (Sheikh et al., 2022). According to Harper et al. (2019) certain regions are already seeing the emergence of a second life market for these EVBs, with demand potentially exceeding supply, indicating a promising market potential. The same study indicates that reusing or repurposing batteries is economically favourable compared to recycling, which further highlights the importance of exploring second life applications. Additionally, achieving a circular EVB SC is significant due to several reasons, including the economic importance of EVBs in EVs, material scarcity concerns, geopolitical SC dependencies and growing regulatory demands for material reuse and recycling (Ribeiro da Silva et al., 2023). As presented in *Figure 2.4*, the second life cycle for batteries is initiated when the capacity falls between 70-80%, and continues until it reaches around 30% of the original capacity (Illa Font et al., 2023; Sun et al., 2018; Sheikh et al., 2022).

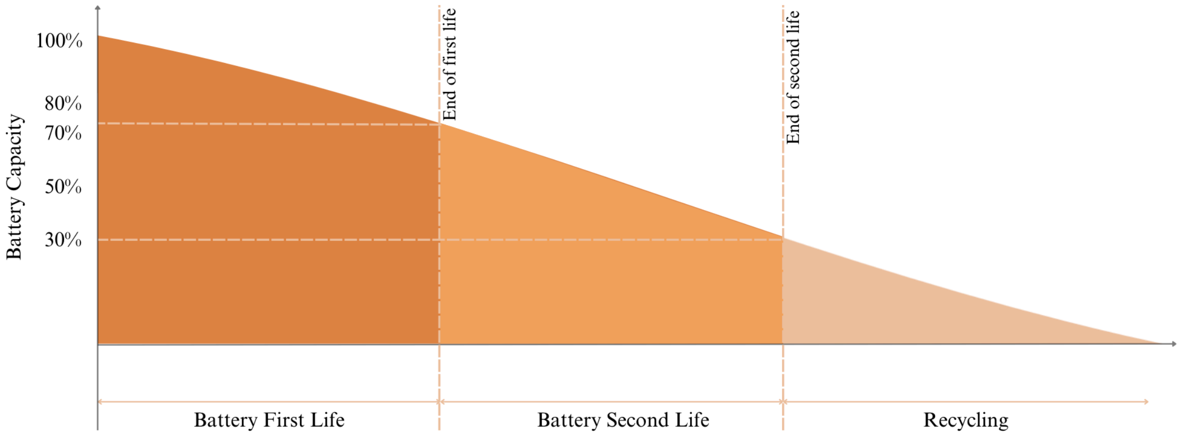

Figure 2.4. Relationship between battery capacity and the EVB life. (Source: Own illustration based on Illa Font et al., 2023)

The concept of complete or partial use of a battery in an application, that is different from its original intended use, is referred to as *battery repurposing* and involves modifying a battery for use in a different context (Sheikh et al., 2022). Multiple studies have examined different aspects of repurposing EVBs, including economic viability, environmental benefits and technological feasibility (Casals, Amante García and Canal, 2019; Sheikh et al., 2022). For instance, Al-Alawi, Cugley, and Hassanin (2022) investigates the potential of repurposed EVBs for residential battery energy storage systems (BESS), emphasising their cost effectiveness and environmental advantages compared to traditional storage solutions. This aligns with findings by Ahmadi et al. (2014), who found that extending the life of EVBs in second life applications could double the reduction in GHG emissions initially aimed for when introducing EVs into the transportation system. Richa et al. (2015) further underscore that reusing batteries can mitigate the environmental impact of producing new batteries by prolonging the life of already existing ones, thus enhancing environmental sustainability.

While battery repurposing offers clear environmental benefits, there are technical and financial uncertainties that delay their deployment and investment in second life applications (Fallah and Fitzpatrick, 2022). The primary technological challenges in the process include reconfiguring the arrangement of the battery cells and creating a BMS adapted to the needs of the new system (Sheikh et al., 2022). Ideally, repurposing EVBs for a second life would not require disassembly as some studies argue that disassembling batteries to the cell level is not technically or economically viable (Casals, Amante García and Canal, 2019). Instead, they suggest using the entire battery pack without any refurbishment. However, in most remanufacturing processes, battery packs need to be disassembled to the module level at minimum to replace faulty cells that have been identified after testing (Harper et al., 2019; Meegoda et al., 2022). This process involves repackaging the batteries and adding necessary electrical hardware and safety systems (Catton et al., 2019). Before repurposing the batteries in new applications, the SoH needs to be identified and the battery needs to be assessed, ensuring that the batteries are suited for repurposing or if they should be recycled directly (Harper et al., 2019; Sheikh et al., 2022). To gain more information about the EoL EVBs technical reliability, Ahmadi et al. (2014) propose that gathering more long term historical data would provide conclusive insights.

Examples of new purposes for EoL EVBs are stationary storage systems, grid-scale energy storage, and powering a vehicle with lower energy requirements (Casals, Amante García and Canal, 2019; Gür, 2018; Sheikh et al., 2022). The demand for energy storage is especially prominent in regions where weak grids need reinforcement, where high levels of intermittent energy sources, like solar and wind, require demand-supply balance, and where there are opportunities for energy trading with the grid and in off-grid applications (Harper et al., 2019). To effectively enable integration of abundant solar and wind energy into power systems worldwide, the use of BESS is crucial (International Renewable Energy Agency (IRENA), 2020). When coupled with renewable generators, batteries help supply reliable and cheap electricity, especially in isolated and off-grid communities that otherwise would have to rely on costly imported diesel fuel for power generation.

Even though using second life batteries offer environmental benefits and are more cost effective, as they are cheaper than their new counterparts, specific challenges need to be addressed before these benefits are realised, according to Sun et al. (2018). These include costs of refurbishing EoL EVBs, including testing and voltage matching the packs, reduced lifespan and efficiency due to degradation in their first life, as well as warranty concerns and societal and regulatory obstacles to adopting second life batteries. The authors of the paper further argue that for the second life market to be viable, it needs to find a balance where the price does not exceed the cost of new batteries or the combined cost of refurbishment and recycling. However, predicting a price of second life batteries remains a key challenge in establishing a second life market due to the lack of a standardised pricing methodology (Fallah and Fitzpatrick, 2022). Numerous studies, like those by Neubauer and Pesaran (2011), Foster et al. (2014), and Casals, Barbero and Corchero (2019), have tried different approaches to develop pricing models based on factors like battery degradation and refurbishment costs. However, these studies often do not address the viability of a second life market at their calculated price points. Similarly, Wu et al. (2020) and Sun et al. (2018) used methods that focus more on general battery features rather than specific second life applications. Below are some of the cost associated with repurposing EVBs summarised based on the presented studies:

- Casals, Barbero and Corchero (2019) estimated EVB refurbishment costs at 104 to409 USD per kWh, while Neubauer and Pesaran suggested 10-40 USD per kWh. According to Sun et al. (2018), refurbishment costs are often cited around 57 per kWh.
- Fallah and Fitzpatrick (2022) found that choosing a lower purchase price for retired batteries can result in profitability comparable to new batteries at market rates in 2022. Using their approach, batteries from four- and 10-year-old vehicles are valued at 26% and 15% of their original cost, respectively.
- The investment cost of a BESS with old batteries is estimated to be 70% of a BESS with new batteries (Fallah and Fitzpatrick, 2022).

Beyond academia, the industry shows increasing interest in second life applications for EoL EVBs. For instance, automotive manufacturers and energy companies are actively exploring ways to repurpose these batteries. Tesla, for example, has initiated projects to use second life batteries for various purposes, including BESS in residential and commercial settings (Murray, 2022).

Recycling

Over time, it is anticipated that the supply of used EVBs will exceed the demand of the second use market (Harper et al., 2019). Consequently, it is important to acknowledge that recycling must ultimately be the fate of all LiBs to avoid landfill disposal, even if they first serve a second purpose. According to estimates made by Statista (2024b) around 90% of all EVBs of BEVs were assumed to be collected, after their first life, within the EU as of 2018. Recycling provides a sustainable way to manage EoL EVBs by recovering materials for new battery production and thus cutting the need for new resources, consequently lowering both the environmental impact and production costs (Sheikh et al., 2022). Once a battery's capacity drops to around 30%, it is recommended that the battery is sent for recycling (Illa Font et al., 2023). Many technologies for LiB recycling have been developed during the past decade (Illa Font et al., 2023; Sheikh et al., 2022), but some studies argue that current processes are limited and are not able to recover the wide range of materials used, with the quality needed for manufacturing new batteries (Dominish, Florin, and Wakefield-Rann, 2021). There are three main recycling routes for LiBs, namely pyrometallurgical, hydrometallurgical and direct recycling (CAS Insights, 2022; Harper et al., 2019). All three methods start with discharging the batteries, to ensure a safe handling, and they are then dismantled either manually or through shredding the batteries into smaller pieces (CAS Insights, 2022). The coming process steps further differentiate the methods:

- Pyrometallurgical recycling involves using high-temperature to convert the metal oxides used in batteries to metals or metal compounds (CAS Insights, 2022; Harper et al., 2019).
- Hydrometallurgical recycling is a chemical process that uses solvents to remove impurities and separate the desired metals from the *black mass* – a powdered mixture of metals (CAS Insights, 2022; Harper et al., 2019; Northvolt, 2024).
- Direct recycling reuses battery materials without extensive processing, where the components are obtained for reusing or reconditioning after disassembly (CAS Insights, 2022).

The environmental benefit of LiB recycling depends on the recycling route and the battery chemistry (Yang, Huang and Lin, 2022). Among the three routes, direct cathode recycling offers the highest environmental benefits by avoiding energy-intensive processes and maintaining cathode structure, although concerns exist about the quality of the recovered cathode materials and commercial feasibility.

Several established processes capable of large-scale recycling of LiB exist, with numerous processes in development (Dominish, Florin and Wakefield-Rann, 2021). The future processes aim to recycle cobalt and lithium and either recycle or downcycle nickel and copper. Technologically, it is possible to recover all four metals at rates exceeding 90%, but recovery rates are limited by the absence of economical drivers or policies promoting the use of recycled materials. As of 2022, it is estimated that only 5% of LiBs are recycled globally with China possessing more than half of the world's recycling capacity (CAS Insights, 2022). However, in response to material scarcity concerns, the industry is increasingly shifting towards using a higher rate of recycled metals. Based on global production in 2019, it is estimated that approximately 500 000 tons of batteries could be recycled. This could result in the recovery of around 15 000 tons of aluminium, 45 000 tons of copper, 60 000 tons of cobalt and 90 000 tons of iron. Moreover, the LiB recycling market is valued at approximately 1 700 million USD, with significant expected growth over the next ten years. *Figure 2.5* highlights the locations of the established and planned LiB recycling facilities in the world, and, as visualised in the figure, there are no recycling facilities on the African continent.

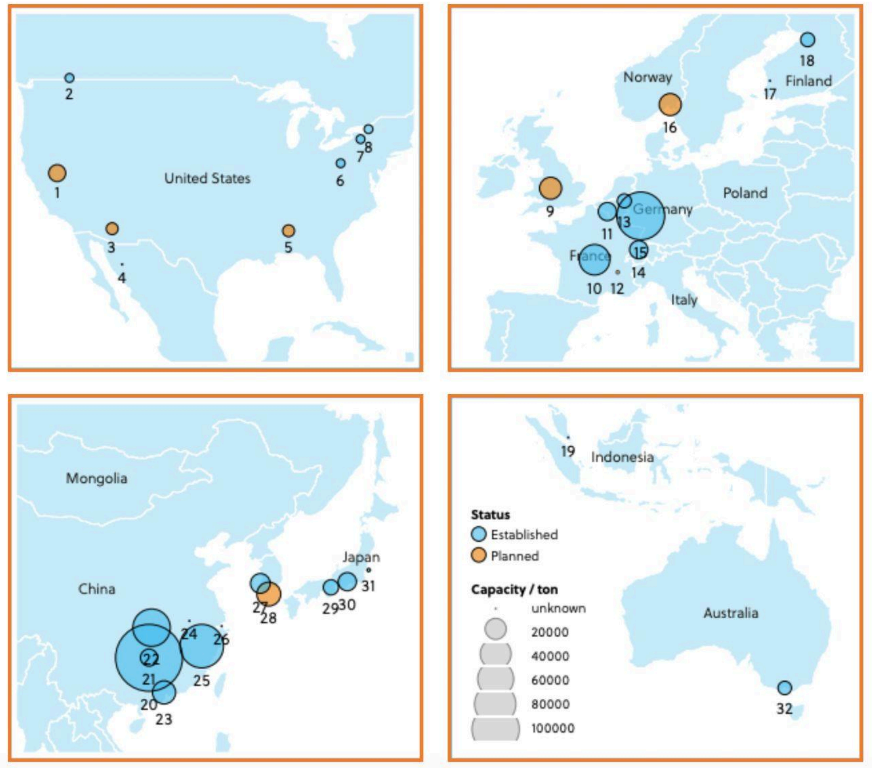

Figure 2.5. Global established and planned LiB recycling facilities as of 2021. (Source: CAS Insights, 2022)

The profitability of LiB recycling relies on two main factors, namely, the costs involved in collecting and processing used batteries and the revenues of selling the recovered materials (Yin, Huang and Ling, 2022). Additionally, the capacity as well as the technological capabilities of the recycling facility affects the recycling cost (CAS Insights, 2022).

2.1.2 Regulations for EoL Handling

In recent decades, there has been a significant increase of production and distribution of electrical and electronic products, leading to a rising volume of waste of electrical and electronic equipment (WEEE) (Bimir, 2020). According to the Global E-waste Monitor (2020) report, 53.6 million metric tons of WEEE was generated in 2019, of which only 17.4% was appropriately managed and recycled (Forti et al., 2020). An estimation by Baldé et al. (2022) indicates that the volume of WEEE will reach 74.7 and 110 metric tons in 2030 and 2050 respectively, if practices are not modified. This emphasises the importance of regulating EVB handling, especially given their tendency to both fires and explosions, when damaged or failing to operate safely, due to their flammable and toxic materials.

Transportation and Packaging

In addition to the considerable size and weight of EVBs, they are also categorised as dangerous goods. More specifically, LiBs are classified as the highest level of dangerous goods, class 9 or *miscellaneous dangerous goods*, by the United Nations Economic Commission for Europe (UNECE) (2019). The presence of diverse materials and their electrochemical characteristics does not only lead to challenges in collecting, discharging, and disassembling EVBs at scale (Zeng, Li and Liu, 2015), but also poses a health risk when left piled up as landfill. There is a heightened risk of fire, release of toxic gases and liquids, along with the potential for electric shocks, which entails severe consequences (Mikolajczak et al., 2011).

The likelihood of the above mentioned risks depends on the EVBs condition, influencing the handling at EoL. There are different ways of categorising batteries based on condition, but the most common one is non-defective (green), defective (yellow) and critically defective (red) (NEFAB, 2020). Green batteries are allowed to be transported under normal conditions, while the transportation of yellow and red batteries is more regulated, including a ban on air transport. The Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), outlines specific packaging requirements for yellow and red batteries, with the purpose of avoiding accidents during transportation (UNECE, 2019). As of February 1st 2024, the ADR applies to 53 authorities (UNECE, 2024), mainly European due to their UNECE affiliation. However, non-European countries like Uganda, bordering Kenya, have also joined the agreement, which is of relevance for the Kenyan case company's expansion plans.

Extended Producer Responsibility

Extended Producer Responsibility (EPR) is an environmental policy approach designed to promote sustainable resource use by extending the producer's responsibility of a product to the post-consumer phase of its life cycle (Brown, Laubinger and Börkey, 2023; Lindhqvist, 2000). The policy aims to increase recovery rates, and minimise waste and leakage by transferring the cost of EoL handling from the general public to the producers and consumers of the products. While EPR is widely adopted in areas like electronics, packaging, and vehicles among the member countries of The Organization for Economic Co-operation and Development (OECD) (Brown, Laubinger and Börkey, 2023), its adoption is growing in developing countries as a strategy to address e-waste challenges (Faible et al., 2023). Several laws and policies have been implemented in developing countries based on, among other directives, the EPR principles. This approach means that original manufacturers have complete responsibility for the entire lifecycle of electronic products, ensuring that waste is collected, transported, and either remanufactured or treated before disposal. However, e-waste management in developing countries is still in its early stages.

The effectiveness and success of implementing the EPR principle in many developed countries can be linked to the accessibility or close proximity of original producers (Kaya et al., 2020) as customers relatively easily can return obsolete electronics to the original producer (Faibil et al., 2022). In Europe, e-manufacturers are prioritising their CSR and EPR initiatives, demonstrating a willingness to go above and beyond to fulfil their obligations (Anderssen, 2022). On the other hand, the absence of original manufacturers is a significant challenge in developing countries (Faibil et al., 2022). Often, electronics are exported to these countries without the corresponding infrastructure or support from the manufacturers. Consequently, the responsibility for managing electronic waste and the implementation of EPR principles, falls primarily on retail firms in these countries. Additionally, in countries with significant informal markets, tracking initial sale is challenging due to untraceable transactions from illegal or informal trade (Manomaivibool, 2009). This complicates efforts to hold retailers accountable for proper electronic waste disposal. Nevertheless, Manomaivibool (2009) suggests that an EPR program can serve as a catalyst for formalising more downstream actors by increasing the demand for licensed waste management entities.

EU Regulations on Batteries and Waste Batteries

As the electrification of the transportation sector continues to advance, regulatory frameworks in dominant markets become important for actors within the global supply and value chain (Melin et al., 2021). Generally, EU regulations compel global compliance. However, due the lack of coordination between regional and domestic policies across important consumption and production regions, the impact of proposed EU regulations are hard to predict. Coordinated efforts to address and understand the effects on global SCs could be made more predictable if done by the global community. For instance, transitioning to open BMS architectures, like battery passports, could mark a shift from current business practices where manufacturers tightly control generated data. The introduction of battery passports aims to provide digital records with detailed lifecycle information and set a baseline for key details required for each battery produced and sold (Weng, Dufek and Stefanopoulou, 2023). By February 2027, all EV and industrial batteries sold in the EU must have a unique QR-coded battery passport, with the aim to enhance environmental protection and increase battery recycling (Stretton, Daphne and Ramkumar, 2023). Global collaboration may lead to sharing of battery information, however it is uncertain how and if locally acquired battery data will be shared across global value chains (Melin et al., 2021). In a unified global market, it is likely that the standard and regulations set by the dominant market will drive compliance. EU regulations stand out as the most advanced environmental standards, significantly impacting environmental stewardship and sustainability efforts, and with its share of the EV market, the EU has the substantial influence to establish standards that could become widely accepted globally.

In 2023, the European Parliament repealed the 2006/66/EC directive and agreed to enforce the 2023/1542 regulation concerning issues related to battery production, use, recycling and disposal as part of the European Green Deal (European Parliament, 2023b). The regulation has the purpose of preventing and reducing the adverse environmental impact of batteries, and ensuring a safe and sustainable battery value chain, taking the carbon footprint of battery manufacturing, ethical sourcing of raw materials and security of supply, and facilitating re-use, repurposing and recycling et cetera into account. The objectives affecting the EoL handling, and more specifically the recycling, of EVBs are summarised as:

- Stricter waste collection targets: for portable batteries for light means of transport batteries – 51% by 2028 and 61% by 2031.
- Minimum levels of materials recovered from waste batteries: lithium – 50% by 2027 and 80% by 2031; cobalt, copper, lead and nickel – 90% by 2027 and 95% by 2031.
- Minimum levels of recycled content from manufacturing and consumer waste for use in new batteries: eight years after the entry into force of the regulation – 16% for cobalt, 85% for lead, 6% for lithium and nickel; 13 years after the entry into force – 26% for cobalt, 85% for lead, 12% for lithium and 15% for nickel.

2.2 Supply Chain Theory

In this chapter, relevant SC theory used in the thesis is presented. The purpose of the thesis is to develop and evaluate actionable strategies enabling an efficient and sustainable handling of EoL EVBs in Kenya, through implementing RL. Addressing the purpose and answering the research question requires a number of SC concepts, which are introduced in this chapter. The most significant concepts involved are CE and RL, which are then complemented with other concepts under the supply chain management (SCM) umbrella: incentive alignment, customer centric approach, supply chain network design (SCND) and successful implementation.

2.2.1 Circular Economy

The global economy has traditionally followed a linear model, characterised by a pattern of production and consumption, where goods are created from raw materials, sold, used, and eventually discarded as waste (Ellen MacArthur Foundation, 2015; European Parliament, 2023a). Despite improvements in resource efficiency, a system based on consumption rather than sustainable use of resources results in losses throughout the value chain (Ellen MacArthur Foundation, 2015). The rapid growth of consumptive economies since the mid-20th century has resulted in increased negative externalities and with the growing global middle class, focusing solely on resource efficiency is not enough. Challenges arising from finite material stocks within the linear model's operating context indicate the need for a fundamental change in the economic operating system. The concept of a CE model is characterised, but not strictly defined, as "*an economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles*" (Ellen MacArthur Foundation, 2015). The differentiation between these cycles is illustrated in the *circular economy butterfly diagram* by the Ellen MacArthur Foundation, presented in *Figure 2.6*.

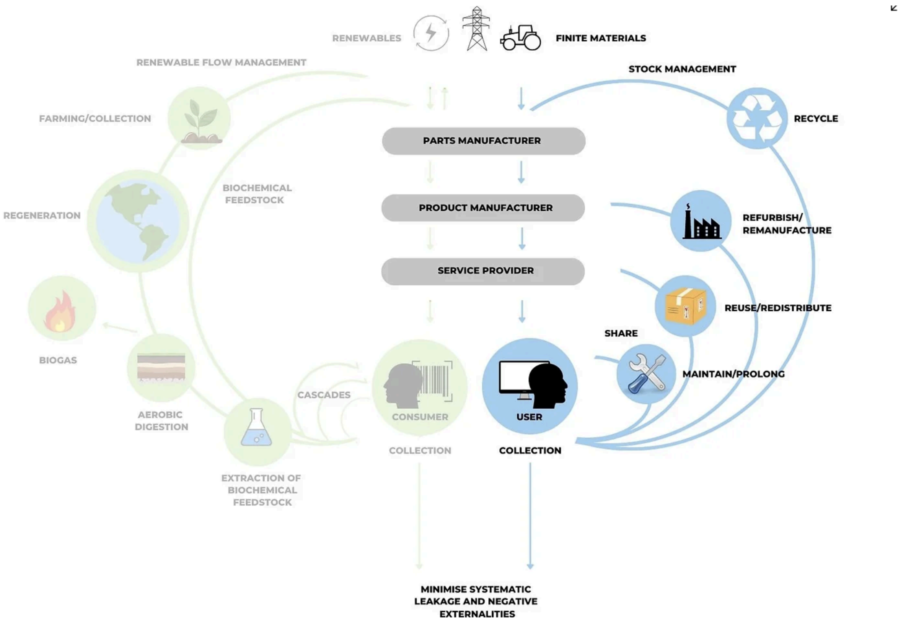

Figure 2.6. Visualisation of the circular economy model, highlighting the technical cycles. (Source: Vrzel, 2022)

The technical cycles, highlighted on the right hand side of *Figure 2.6*, include management of non-renewable abiotic resources and flows of materials that cannot return to the biosphere (Navare et al., 2021). As abiotic resources are finite, the technical cycles are designed to maximise the use of these resources within the technosphere through maintaining/prolonging, reusing/redistributing, refurbishing/remanufacturing, and, finally, recycling. The butterfly diagram consists of smaller loops surrounded by larger ones, where a tighter circle represents a more valuable strategy (Ellen MacArthur Foundation, 2015). The sharing of products, representing the first port of call in the technical cycle, refers to increasing their utilisation and, in turn, decreasing the number of products entering the market (Ellen MacArthur Foundation, 2022). The inner circle emphasises the importance of maintaining a product, and keeping it at a high quality, to prolong its usable life. The second circle, reusing/restributing, includes other ways of making sure that the product is kept in use, through reusing it repeatedly or diverting it from its intended market respectively. Thereafter, the model suggests either refurbishing or remanufacturing. Refurbishing includes, for instance, repairing or replacing components, to return a product to a good working order. Remanufacturing, on the other hand, is often associated with higher investment costs and is performed once the product can no longer remain in circulation in its current state. Remanufactured products tend to have the same, or higher, level of performance as a newly manufactured one. Extending the life of products by maximising the number of cycles and/or the time in each cycle helps saving material, energy and labour required for creating new items (Ellen MacArthur Foundation, 2015). The largest circle represents recycling and is the final step in the technical cycle. As recycling involves losing the embedded value of a product when separating it into its basic materials and components, prioritising the inner circles is recommended (Ellen MacArthur Foundation, 2022; Vrzel, 2022).

The CE model is closely related to the waste hierarchy, which was initially introduced as part of the European Union Waste Framework Directive, 2008/98/EC, in 2008 (European Parliament, 2008; Zhang et al., 2022). The waste hierarchy consists of five steps: prevention, preparing for re-use, recycling, other recovery, and disposal, that are to be prioritised in the mentioned order. Both the waste hierarchy and CE model consider the entire life cycle of a product, including the pre-use, use and post-use phase. Despite the models' joint philosophy of improving resource efficiency and reducing the harmful impact of waste, through minimising production, optimising design and repurposing to prolong the total life cycle, they differ as the waste hierarchy allows disposal, which the circular economy model does not (Ellen MacArthur Foundation, 2015; European Parliament, 2008; Zhang et al., 2022).

2.2.2 Reverse Logistics

RL enables the efficient and effective retrieval of materials from customers, playing a vital role in closing the SC loop and implementing CE practices (Azadnia, Onefrei and Ghadimi, 2021). Logistics refer to the operations taking place within a SC, which is defined as *"a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer"* (Mentzer et al., 2001). As stated in the definition, the term refers to the flows between a source and an end user. Products will keep flowing towards the end user but, with the purpose of recapturing some of the used products value, an increasing volume of products are moving back to the original equipment manufacturer or to companies working with either remanufacturing or recycling (Nikolaidis, 2013, p. 3). These flows are within the scope of reverse logistics which, based on the definitions gathered by de Brinto and Dekker (2002), is defined as *“the process of planning, implementing and controlling the flows of raw materials, in-process inventory, finished products and information, from the point of consumption to the point of recovery or proper disposal”* in the thesis.

When considering the adoption of RL practices, there are various factors for organisations to contemplate (Waqas et al., 2018). Researchers have identified various barriers to implementing RL in developed countries, including high processing, warehousing and transportation costs, as well as deficient waste management. Additionally, factors such as insufficient time commitment, absence of integrated corporate SC strategies towards RL, low awareness about RL operations, and a limited interest from top management in RL activities and functional priorities are identified. These barriers vary in severity depending on the organisation. Even within an organisation, the treatment method for addressing the same barrier might vary depending on resources, strategies and capabilities. Different countries have adopted different practices to encourage RL and support sustainable development. (Waqas et al., 2018)

Because of differences in economic growth, approaches to implementing RL vary between developed and developing nations. However, as implementation of RL is still in its early phases in developing nations, valuable lessons can be drawn from the experiences of developed nations. Based on extensive literature reviews performed by Waqas et al. (2018) and Azadnia, Onefrei, and Ghadimi (2021), the different barriers to RL are divided into eight categories:

1. Financial & Economical Related Barriers
2. Knowledge & Experience Related Barriers
3. Law & Regulation Related Barriers
4. Management & Organisational Related Barriers
5. Infrastructure & Technology Related Barriers
6. Environmental Related Barriers
7. Market & Social Related Barriers
8. Policy Related Barriers

Waqas et al. (2018) studied RL barriers within the context of a developing country and identified the most significant ones within each category. The main *financial and economic related barriers* for implementing RL in a developing country include the absence of initial capital, high adoption costs and low return on investments. *Knowledge and experience related barriers* include lack of skilled professionals in RL, lack of knowledge and inaccurate forecasting. In terms of *laws and regulations*, main barriers are absence of government supportive policies, inadequate laws on product returns of EoL and lack of customer awareness about returning used products. *Management and organisational related barriers* concern poor organisational culture, insufficient top management commitment and no cooperation with RL professionals. Lack of human resources and new technology, along with deficient infrastructure, are significant barriers within the *infrastructure and technology* category. Lack of awareness of environmental law and no environmental specific goals are the highest weight barriers in the following category. *Market and social related barriers* include insufficient community pressure and underdeveloped recovery marketplaces. For the last category, the barriers are mainly driven by lack of Corporate Social Responsibility (CSR) and ethical standards. (Waqas et al., 2018)

Azadnia, Onefrei, and Ghadimi (2021) focused on investigating barriers within the context of RL for EoL EVBs. According to their study, the high upfront costs of establishing infrastructure and remanufacturing centres, especially in the EU where labour costs are high, and the rate of returned LiBs creates debate about financial feasibility. Uncertainty of demand and returns as well as product quality reliability for returned EVBs is one of the main barriers within the category referred to as *law and regulation related barriers*. Inadequate commitment from management is also a barrier for RL for EVBs, due to absence of mandatory requirements to adopt and implement RL. As for *infrastructure and technology related barriers*, they include insufficient design for recycling and disassembly, as well as a lack of efficient infrastructure and technology, in regards to, for instance, collection, sorting, disassembly, and recycling sites. Limited information-sharing technology, tracking systems, and labelling standards for EVBs further hinder efficient RL implementation. In terms of *market and social related barriers*, the main one is lack of customer interest in recycled or remanufactured EVBs. Moreover, *policies* play important roles in implementing RL for EVBs and academia discussions highlight that inadequate and slow-changing legislation for EoL management hinder the implementation of RL. The authors of the paper also discuss how extending EPR across borders might pose a challenge, due to the global nature of the EVB SC and differences in policies and regulations among different countries. (Azadnia, Onefrei, and Ghadimi, 2021)

2.2.3 Supply Chain Management

Before addressing other relevant concepts and theories within SCM, a better understanding of the term is needed. According to Mentzer et al. (2001), SCM is defined as the *"systematic, strategic coordination of the traditional business function and the tactics across these business functions within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole"*. With the definition of SCM now presented, another four relevant concepts related to SCM are introduced.

Incentive Alignment

To retrieve EoL EVBs through implementing a return flow, it is possible that some kind of incentive is required. An incentive is a way of urging individuals, companies or company functions to act in a preferred way. Generally, incentives fall into three categories: economic, social and moral incentives, which can be used separately or in combination to induce motivation. Incentive alignment is defined as designing *"proper incentives that motivate players in aligning individual decision-making more closely to the overall goal by sharing costs, distributing risks, and sharing benefits"* by Simatupang and Sridharan (2005), who identify misaligned incentives as a source of SC discontent. The concept of incentive alignment is based on the assumption that individual members of a SC base their decisions on the compensation they receive from others. If the compensation is not motivating the members to make decisions in line with the overall goal, they will be tempted to deviate from the agreement to maximise their own short-term winning, highlighting the importance of properly designing an incentive scheme throughout the SC. Throughout the process of aligning incentives, Simatupang and Sridharan (2005) highlight the importance of including the management teams as it is of high importance to have a broad understanding of all functions of the companies in the SC to tackle issues related to misalignment.

One industry that applies economic incentives for retrieving worn products is the home electronics industry (Apple, 2023; Samsung, 2024). When customers return their old phones, computers, or similar, they receive a discount on a new product, determined by the condition of the returned device. This not only encourages responsible disposal of old electronics but also promotes reuse and recycling. To exemplify, Apple has launched a trade-in program where you get 30-630 USD to spend on a new Apple product, when trading in your old phone (Apple, 2023). If the product is in a condition unsuitable for repurposing, Apple offers to take it back at no cost and ensures it is properly recycled.

Customer Centric Approach

In the current era, characterised by global competition, short product life cycles and easily disappointed customers, companies are highly dependent on finding ways to improve their performance to remain relevant on the market (Madhani, 2019). Focusing on the customer, through implementing a customer centric approach, is one of the performance enhancing drivers that companies have started giving more attention to. A company's SC performance significantly impacts its strategic performance, which is why it is of great importance to align the SC with the general corporate strategy of the company (Sabri and Verma, 2015), leading to an increased interest in the customer centric SC strategy (Madhani, 2019). According to Madhani (2019), a customer centric SC strategy includes incorporating the customer throughout the SC instead of solely seeing them as the final step of the chain. To do so, the author presents four competitive priorities: responsiveness, resiliency, reliability and realignment. Through succeeding within these four areas, companies can gain a competitive advantage through getting both market and customer demand insight. However, to know how to prioritise the 4Rs mentioned, it is of high importance to understand the market the company operates within and the needs of their customer segments.

Supply Chain Network Design

SCND determines the structure of a SC, impacting both its performance and costs (Farahani et al., 2014). Broadly speaking, the network design problem involves configuring the nodes within a product flow network, including everything from sourcing the raw materials to the final consumption points (Ballou, 2001). It involves making decisions with regards to the number of tiers within the SC as well as the size, capacity and location of facilities within the SC, including both tactical aspects like distribution, transportation, and inventory management policies, as well as operational aspects like meeting customer demands (Farahani et al., 2014). Market conditions and business requirements, and other external factors, often influence some of these variables. The aim of SCND is to design an effective network structure for entities in new chain's or redesigning existing chains to enhance their value. According to Ballou (2001) redesigning a SC frequently can reduce cost with 5-15%.

Successful Implementation

According to Sabri and Verma (2015) only 30% of the SC transformation projects succeed, and the failures can be categorised into two groups: lack of knowledge and preparation of the transformation, and poorly managed people aspects. Both categories originate from lacking change management, showing the correlation between the success rate of transformation projects and the degree of effective change management. Essentially, the aim of change management is to *"internally implement the optimal adaptation to external changes derived from strategic* *management"* (Lauer, 2021, p. 4). In their article, Sabri and Verma (2015) identify five success factors of change management within SCs: executives commitment and visible support, having a comprehensive SC strategy, using a proven change management methodology, articulating the case for change, and maintaining energy and involvement.

A classical framework for planned change was developed by Lewin in 1947, and consists of three steps: unfreezing, movement, and refreezing (Lauer, 2021, p. 66; Hussain et al., 2018). With the vision of moving from the current unsatisfactory state to a future identified desired state, the organisation needs to become ready for change, implement the change and, lastly, make sure that the organisation keeps working in accordance with the new status quo. Based on the identified challenges for successful transformation, Sabri and Verma (2015) presentes an eight step framework, standing on the same three pillars as Lewin's framework, for successful SC transformation projects using SC change management. Also included in their framework, presented in *Figure 2.7*, are their five identified success factors to maintain throughout the transformation project.

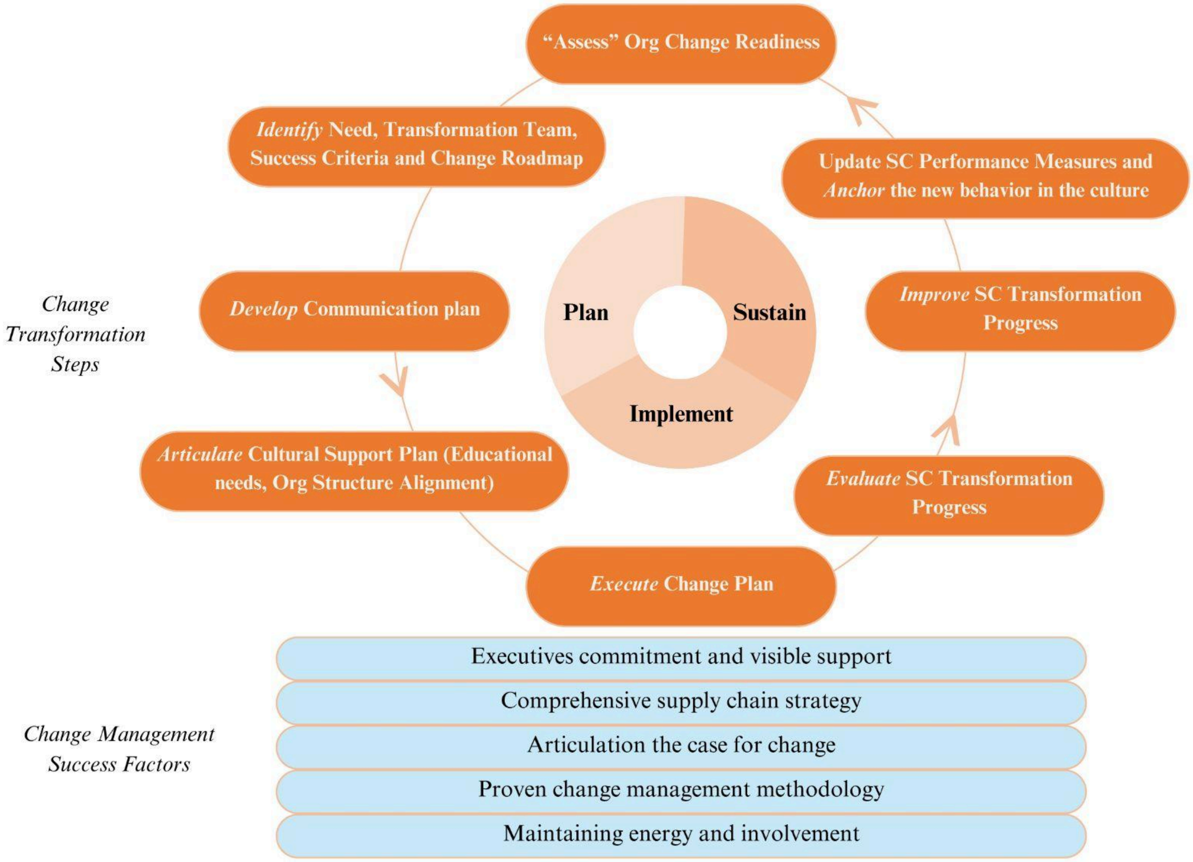

Figure 2.7. Practical change management framework for SC transformation projects, including five success factors. (Source: Own illustration adopted from Sabri and Verma, 2015)

2.3 Kenyan Market Conditions

As the purpose of the thesis is to develop and evaluate actionable strategies enabling an efficient and sustainable handling of EoL EVBs in Kenya, it is crucial to understand the Kenyan market.

This chapter gives an overview of the Kenyan economy, energy market, transportation sector, EV market, and waste management practices, all of which are of high importance for fulfilling the purpose and answering the research question.

2.3.1 Economy

Kenya is a developing country, located in the Sub-Saharan region in Eastern Africa, with a population of around 54 million (Ministry of Foreign and Diaspora Affairs, n.d; World Bank, 2022). With a real GDP growth of 5% in 2023 and projected growth between 4.5-5.2% in 2024, the country has emerged as one of the fastest growing economies in the region (World Bank, 2023b). The country has a market-based economy and is often considered the economical, financial, commercial, and logistical hub of East Africa, which has made Kenya successful in attracting both exporters and investors (Sustainable Inclusive Organisation, 2021). However, the Kenyan economy is highly dependent on the informal sector, which, according to estimations made by Murunga, Muriithi, and Were Wawire (2021), has expanded progressively to comprise 32% of the country's GDP. The informal economy is, according to the International Labour Organization (2024), referred to as *"all economic activities by workers and economic units that are – in law or in practice – not covered or insufficiently covered by formal arrangements".* While the informal sector is suitable for creating job opportunities in Kenya, accounting for approximately 77% of the country's total workforce, it is also linked to rising tax burdens, poor governance, and high levels of corruption within the public sector (Murunga, Muriithi and Were Wawire, 2021).

2.3.2 Energy Market

During the last decade, Kenya has aggressively tried to increase access to the power grid, having more than doubled the access from 36.2% of the population in 2012 to 76.5% in 2021 (World Bank, 2023a). This makes Kenya one of the most eminent countries in the entire Sub-Saharan region, where the average access increased from 36.7-50.6% during the same period. Kenya also has remarkable resources for renewable energy and the government is prioritising the construction of geothermal, wind, and solar energy plants for grid-interconnected projects (Energy and Petroleum Regulatory Authority (EPRA), 2023). This initiative aims to accelerate progress towards achieving a complete transition to renewable energy by 2030. By December 2022, the installed capacity of renewable energy sources represented around 76.9% of the total installed capacity. During the same period, approximately 87% of the total energy generated originated from renewable sources. The majority of the green energy in Kenya originates from geothermal energy, with Kenya producing most in Africa, and seventh globally as of 2022), followed by hydropower, wind power and, lastly, solar power. However, the country has seen a trend in increased installation of solar photovoltaic (PV) systems for both industrial and commercial use. *Figure 2.8* provides an overview of the installed capacity of renewable energy categorised by technology as of December 2022.

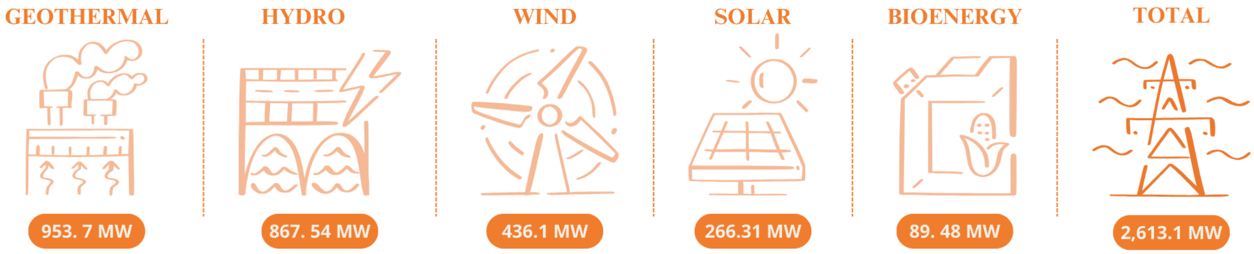

Figure 2.8. Installed renewable energy capacity as of December 2022. (Source: Own illustration based on EPRA, 2023)

In Kenya, a significant challenge facing many companies is frequent power outages. In 2018, 80% of Kenyan companies experienced monthly power outages, far surpassing the global average of 50% (World Bank, 2018). According to the EPRA (2023), the power outages occur an average of 3.4 times per month, with each outage lasting around eight hours. The transmission and distribution network is facing severe constraints, especially during peak hours (Ministry of Energy, 2018). The issue is partly due to the system becoming increasingly outdated and therefore unreliable, which in turn poses challenges for companies in pursuit of affordable, clean, and reliable energy sources. Moreover, during power outages, the majority of PV systems tied to the grid automatically deactivate if they lack connection to a BESS, making them non-functioning during these hours (Ansari, 2021). This occurs due to various reasons, including inverter functionality, compliance with global technical standards, and safety regulations.

2.3.3 Transportation Sector

The transport sector, predominantly road-based, is the second-largest contributor to the country's GDP at about 8%, due to significant local and international infrastructure investments (Kamau, 2021; Kwoba and Mettke, 2020). A substantial part of the Kenyan transport sector operates within the informal economy, including public service modes such as the widely used minibuses commonly referred to as *matatus* and motorcycles, known as *bodabodas* (Kamau, 2021). A study from Conzade et al. (2022) found that over 90% of two-wheelers are purchased for commercial purposes, primarily serving as taxis or for delivery services. According to Kenya Institute for Public Policy Research and Analysis (KIPPRA) (2022) these motorcycle services serve as an important source of employment, especially for the youth population. Moreover, bodabodas facilitate easy urban movement and provide crucial transport in rural areas with limited alternatives and poor road networks. Furthermore, the sector generates over one million direct jobs and the government collects an estimated 60 billion KES annually in fuel taxes from the sector, emphasising its substantial contribution to the social and economic development of Kenya. The existing transport infrastructure is insufficient, fragmented, and inaccessible, especially in the rural areas (Kwoba and Mettke, 2020). This creates various challenges, including issues with road safety, fatalities, accessibility problems, and urban congestion.

2.3.4 Sub-Saharan Electric Vehicle Market

The transportation sector is responsible for 10% of Africa's total GHG emissions, and the figure is expected to rise in line with the expanding vehicle fleet in Sub-Saharan Africa (Conzade et al., 2022). In South Africa, Kenya, Rwanda, Uganda, Ethiopia, and Nigeria, accounting for around 70% of annual vehicle sales and 45% of the region's population, the vehicle park is forecasted to increase from 25 million in 2022 to 58 million by 2040. With the expanding vehicle fleet, Sub-Saharan Africa faces the challenge of promoting sustainable mobility while also avoiding becoming a dumping ground for the world's used internal combustion engine (ICE) vehicles, as 40% of all globally exported used vehicles end up on the continent. Several governments in the region are setting targets for vehicle electrification and offering incentives for EV adoption. Kenya, for instance, has implemented measures like establishing EV standards, reducing excise tax on EVs from 20% to 10%, and collaborating with partners like UNEP to pilot e-mobility programs (International Trade Administration, 2022). In addition, there is an emerging start-up ecosystem specifically dedicated to EVs, with a focus on electric two-wheelers, taking place in the region (Conzade et al., 2022).

As of 2022, the total cost of ownership of owning an EV is advantageous compared to owning an ICE vehicle, however, the initial up-front costs are still a barrier (Conzade et al., 2022). The economic benefits improve with vehicle usage because of lower operating costs, leading to commercial vehicles being suitable for early transition. The gap is less prominent when it comes to two-wheelers as they, unlike the other vehicle segments in the Sub-Saharan region, typically are bought new. Moreover, since most two-wheelers are purchased for commercial use, there is a relatively frequent fleet turnover with urban owners in Kenya, on average, purchasing a new one every two to three years. This has led to several emerging start-ups focusing on EV two-wheelers in the region (International Trade Administration, 2022; Conzade et al., 2022). Nonetheless, there are still several challenges that need to be addressed, including the higher up-front price, uncertainty about battery lifespan, and the cost of changing the used batteries. According to Purwani et al. (2022), increasing the volume of battery production and developing batteries with new materials with greater energy density, are solutions that could make EVs more affordable. In addition, a swap model for the batteries is another solution that not only shortens the battery charging process but also contributes to reducing the up-front cost of EVs. The idea is that by offering EV sales without a battery, the battery belongs to the EV producer or a third party, alleviating the financial burden on consumers and making EVs more accessible to a wider range of buyers.

For Kenya to fully embrace the development of the EV industry, there is a need for enabling infrastructure (International Trade Administration, 2022). The required enabling infrastructure includes improving the access and reliability of electricity, while also focusing on accommodating an increased domestic consumption during off-peak hours, as vehicles are expected to be charged at nighttime (Conzade et al., 2022). Beyond an adequate charging infrastructure, electric two-wheelers may also benefit from the previously mentioned battery-swap model, allowing for quick replacement of depleted batteries at designated swap stations.

2.3.5 Waste Management

African countries are significant destinations for WEEE, both through formal and informal channels (Bimir, 2020). The import to the continents accounts for 19% of its total e-waste generation, which is the highest percentage in the world (Baldé et al., 2022, p .36). Moreover, out of the 2.9 million metric tons of e-waste the continent generated in 2019, only 1% was treated in environmentally sound facilities. This limited capacity, primarily due to the inadequate infrastructure, highlights Africa's struggle to manage the large quantities of imported e-waste through formal channels. The flow of incoming e-waste to the continent is visualised in *Figure 2.9.*

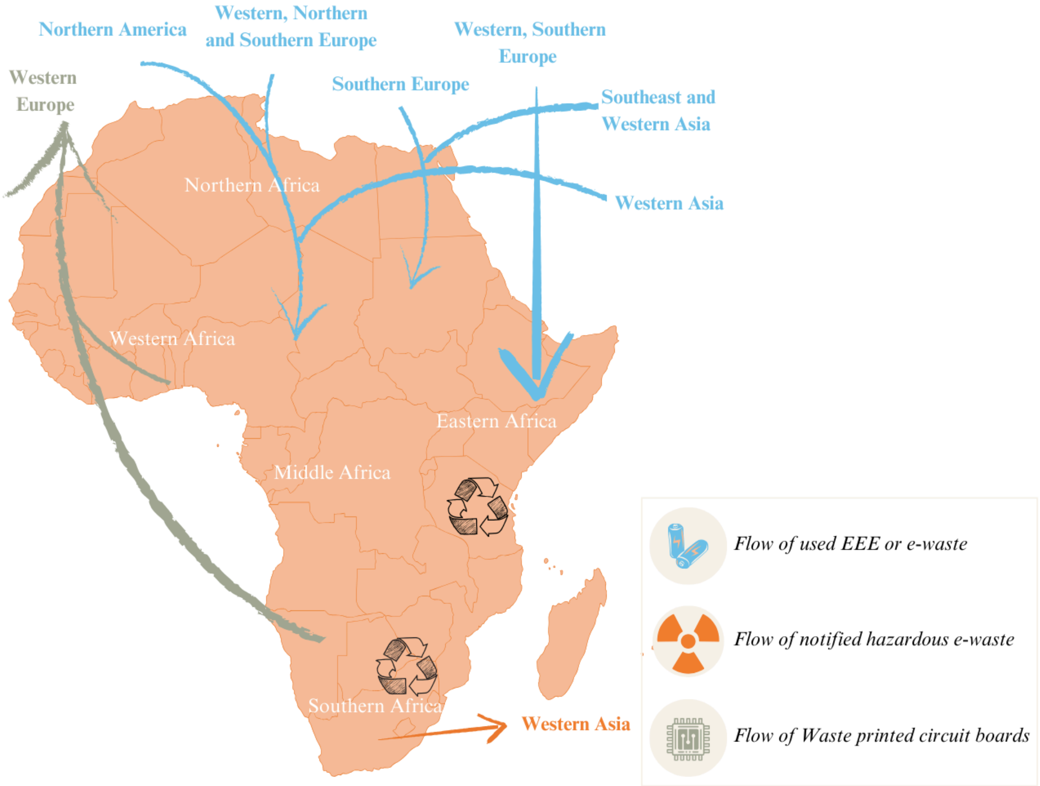

Figure 2.9. Flow of e-waste. (Source: Own illustration based on Baldé et al., 2022)

There are various international efforts aiming to regulate the global e-waste flow, like the Basel Convention established in 1989 that was developed to address concerns about importation of toxic wastes to developing nations. The convention, with its 189 parties, stands as the only global treaty governing the transboundary movement and disposal of hazardous waste (Baldé et al., 2022). Other initiatives include legislations regarding notification for shipping WEEE, a ban on sending hazardous waste to non-OECD countries, and the design of products to enhance recycling rates, all developed by the EU. Additionally, African Union member-states have formulated the Bamako Convention to address hazardous waste inflow into the African countries. Despite these efforts, the challenge of managing e-waste persists and poses serious environmental and health concerns in developing countries. The issue with WEEE is not only the presence of waste but also the lacking infrastructures and standardisation for proper and environmentally sound e-waste management (Baldé et al., 2022; Nnorom and Odeyingbo 2020; Otieno and Omwenga, 2016). As a consequence, there is a reliance on informal sectors using crude dismantling and backyard recycling techniques. Uncontrolled practices, such as open burning of cables to recover copper wire and the disposal of e-waste at dumpsites, are widespread and these practices lead to environmental contamination, exposure of humans to harmful chemicals, and resource loss.

Despite Kenya being a signatory to most international conventions on e-waste, local e-waste management practices in the country are weak (Bimir, 2020; Otieno and Omwenga, 2016). Furthermore, the existing regulatory and legislative frameworks are ineffective and as the effectiveness of global and regional conventions relies on strict national control laws, Kenya faces similar challenges as many other developing countries. The main legislations addressing e-waste in Kenya are the Environmental Management and Coordination Act 1999 and the Waste Management Regulations of 2006 (Bimir, 2020). Even though regulations regarding handling, storage, transportation, segregation, and destruction of harmful materials and waste exist (Kenya Law Reports, 1999/2012, p. 49), they are, according to Otieno and Omwenga (2016) ineffectively implemented.

Moreover, due to the government not prioritising the implementation of sufficient infrastructure and allocating resources for handling WEEE, the handling of e-waste in Kenya, as in many other developing countries, falls under the informal sector (Schluep et al., 2012). Despite the challenges and negative impacts caused by e-waste, several benefits can be identified, including job creation, revenue generation, and the production of waste bi-products (Otieno and Omwenga, 2016). Some products can be dismantled, and valuable materials, especially metals, can be rescued, reused or reclaimed for other purposes, including the informal manufacturing sector (Bimir, 2020). As the majority of e-waste end up on one of the hundreds dumpsites existing in the country (Kenya Ministry of Environment and Forestry, 2019), with the largest one being Dandora dumpsite in Nairobi (Kiarie- Kimondo, 2022), many of these materials are collected from the sites (Bimir, 2020). The dumpsites, often underutilised and poorly managed, present significant environmental and health risks, particularly for vulnerable populations.

2.4 Theoretical Framework

In the theoretical background, relevant literature within three fields is introduced, where the intersection between EVBs and SC theory, contextualised within the Kenyan market, provides valuable insight in approaching the purpose of the thesis. The combined insights from each sub-chapter outline the theoretical framework of the thesis, which, in combination with insights from the empirical studies, is used when further exploring how the case company could benefit from implementing RL of their EVBs. To build on the visualisation of the theoretical framework presented in *Figure 2.1*, where the thesis' area of analysis is highlighted as an intersection between the three areas, *Figure 2.10* summarises the main parts within each sub-chapter.

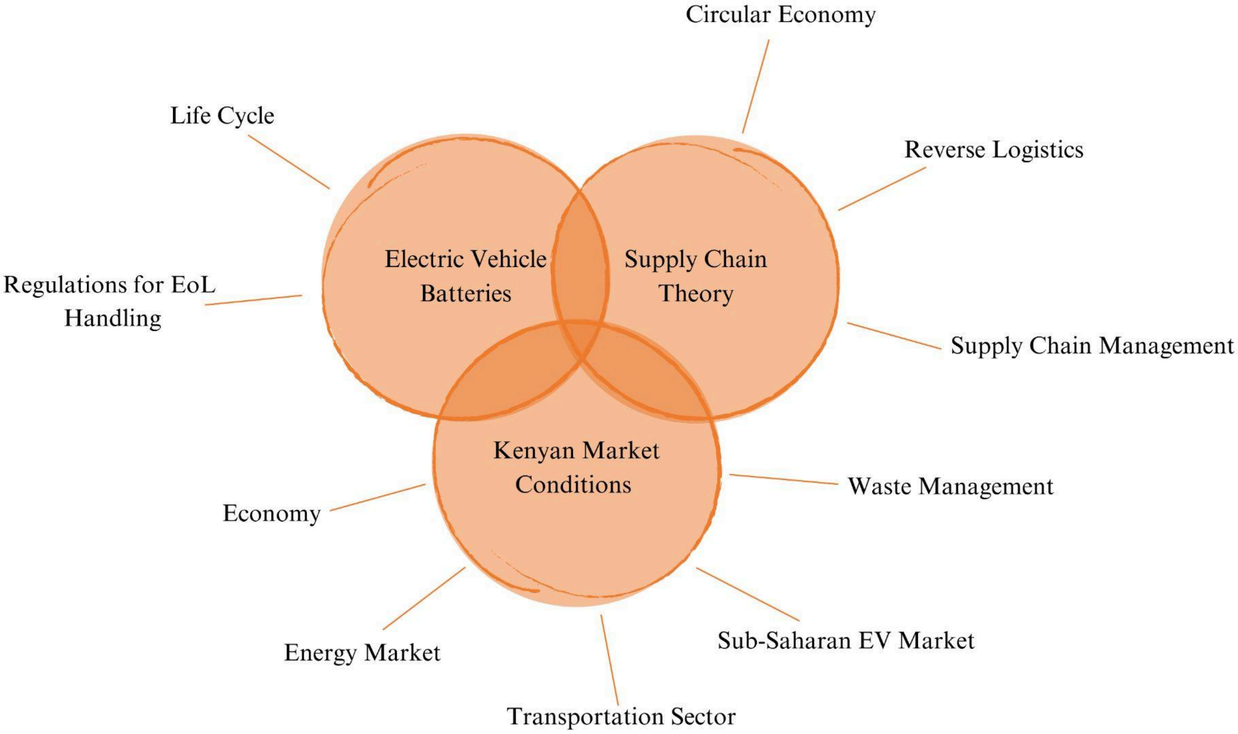

Figure 2.10. Main parts within each part of the theoretical framework supporting the thesis.

Initially, relevant theory about EVBs is presented. In addition to shortly presenting the EVB characteristics, emphasis is put on their life cycle, and especially their potential second life cycle and recycling opportunities. With the purpose of presenting an EoL solution for the EVBs of an EV producing company, the EoL opportunities are combined with relevant regulations affecting the handling of the batteries. From a theoretical point of view, there are clear cases for both second life applications and recycling of EVBs, where environmental, economical, and geopolitical arguments are presented. However, the hazardous nature of EVBs and the uncertainty of the second life market complicates the EoL handling, which has to be considered when suggesting a RL setup.

Secondly, the SC theory chapter details the concepts of CE and RL, and further provides a handful of concepts to be considered when setting up a reversed EVB SC. Understanding CE is essential for prioritising applications at EoL from an environmental point of view. A prerequisite of enabling CE of EVBs is to implement RL, why the concept is both thoroughly described and problematised in terms of implementation. Aligning the SC strategy with the general corporate strategy is an important aspect in ensuring long-lasting success in implementing an EoL setup. Both incentive alignment and a customer centric approach highlight the significance of understanding what drives customer satisfaction and keeping this in mind when designing the SC. Lastly, SCND and successful implementation presents aspects to keep in mind when setting the structure of the reversed SC and how to work within the organisation to succeed with the transformation project. These are all important aspects when implementing a RL setup for an EV producer, as it requires strategic alignment as well as a deep understanding of both intra organisational and customer requirements.

Figure 2.11 is a modified version of the technical cycles of the CE model, described in *chapter 2.2.1*, adapted to specifically accommodate the characteristics of EVB life cycles presented in *chapter 2.1.1*. *Prolong* refers to increasing the first life of an EVB during production, whereas *repair*, including both refurbishing and remanufacturing, means increasing the lifetime while the battery is already in use. *Repurpose* is a prerequisite for the battery to enter its second life, and includes rebuilding the EVB to suit a new application. The final loop, *recycle*, is all about retrieving the raw materials of the EVB. Given that the thesis focuses on RL and EoL handling, and that battery manufacturers are therefore not part of the scope as clarified in *chapter 1.5*, the model's innermost loop will not be further addressed.

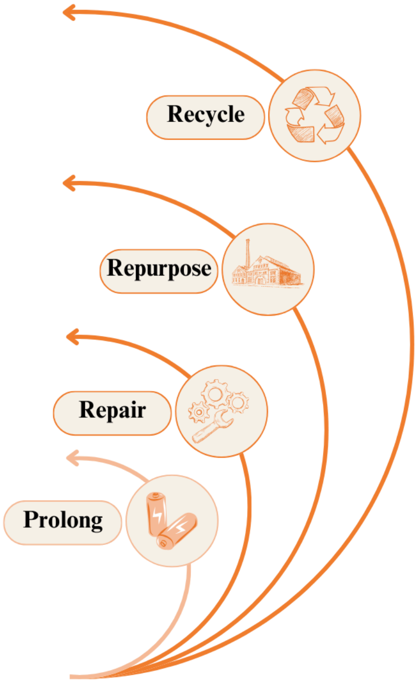

Figure 2.11. Modification of the CE model's technical circles, suiting the EVB life cycle.

Finally, the theoretical framework presents aspects of the Kenyan market conditions affecting the EoL handling of EVBs. In addition to a short introduction of the Kenyan economy, the energy market, transportation sector, EV market, and waste management system are described. Understanding the operating context is of high importance when designing a RL setup, and as EoL handling of EVBs is in its early phases globally, the local market insights are combined with current best practices and SC theory to explore potential solutions feasible for Kenyan actors.

3. Methodology

The methodology chapter outlines how the thesis is designed and conducted. It aims to establish transparency and coherence between the research question, the objectives of the thesis, and its findings. First, the research strategy is explained and argued for, which is followed by an explanation of the research design, including a presentation of the case company and the unit of analysis. Thereafter, the data gathering process as well as the data analysis and evaluation are explained. The chapter concludes with a brief discussion on the research quality and ethics of the thesis.

3.1 Research Strategy

The initial step of fulfilling the research purpose of developing actionable strategies enabling an efficient and sustainable handling of EoL EVBs in Kenya, is applying a general research strategy. Based on the purpose of the thesis as well as the characteristics of the research question, an exploratory strategy is most suitable. Exploratory studies aim to get an in-depth understanding of how something works or is performed (Höst, Regnell and Runeson, 2006, p. 29). This is applicable for the thesis, as a deep understanding of EoL EVB handling, RL and the Kenyan market is needed to fulfil the purpose. The general research strategy is further supported by arguments originating from Yin (2003). Firstly, an explorative strategy is useful when investigating an area where the established knowledge is scarce. This is true for the emerging Kenyan EVB market, where a common strategy for handling EoL batteries, and the RL surrounding it, is not yet adopted. Furthermore, the goal of an exploratory study is to develop relevant hypotheses and proposals for further investigation (Yin, 2018, p. 40). This is applicable as the area of study is fairly unexplored, which indicates that further studies would be beneficial when developing standards for how to implement RL of EoL EVBs in the region.

For an exploratory study, various research methods can be applied, including surveys, experiments, archival analysis, history, and case studies (Yin, 2003, p .6). This thesis is based on a case study, which is a comprehensive examination of a historical or current phenomenon with insights drawn from various sources of evidence (Leonard-Barton, 1990). It includes data gathered through direct observation, systematic interviewing, and consultation of a variety of academic journals. The decision of adopting a case study for the thesis aligns with Yin's (2003, p. 5) criteria for selecting a research method. The three criteria include the type of research question, the extent of control the investigator has over behavioural events, and the degree of focus on contemporary as opposed to historical events. Initially, the thesis' research question is a "how" question, commonly addressed through case studies, histories, or experiments (Yin, 2003, p. 5). Secondly, there is no need to control the events for addressing the question, eliminating the experimental approach. Lastly, the studied events are contemporary as a current setting of an emerging market is being studied. A case study has the benefit of being flexible, meaning that it can be continuously adapted based on changed conditions and extended knowledge during the period of research (Höst, Regnell and Runeson, 2006 pp. 31-34), which is advantageous when performing research on an unfamiliar market.

Furthermore, Yin (2003, p. 39) classifies four types of case studies, differentiated by their use of a single- or multiple case design and whether they use single or multiple unit(s) of analysis

(UoA), referred to as either holistic or embedded. This thesis adopts a holistic single case study approach, as highlighted in the upper left corner of *Figure 3.1*, focusing on Roam Electric within the Kenyan market context. However, to enrich the analysis, comparisons to the European context, representing a more mature market, are made in order to provide deeper insights and a broader perspective of an emerging second life market. According to Leonard-Barton (1990), there are both advantages and disadvantages with doing a single case study. Using a single case company allows for a more in-depth understanding of the company situation, while being a preferred choice when the time and resources available are limited. On the other hand, it limits the generalisability of the conclusions drawn and makes the study more prone to biases, such as misjudging the representativeness of the available data. A holistic case study proves beneficial when clear subunits are challenging to identify or when the underlying theory is holistic (Yin, 2003 p.45). However, it is important to recognise that this design may risk being abstract and lack clear measurements. Conversely, an embedded design may neglect the larger UoA, focusing solely on subunits.

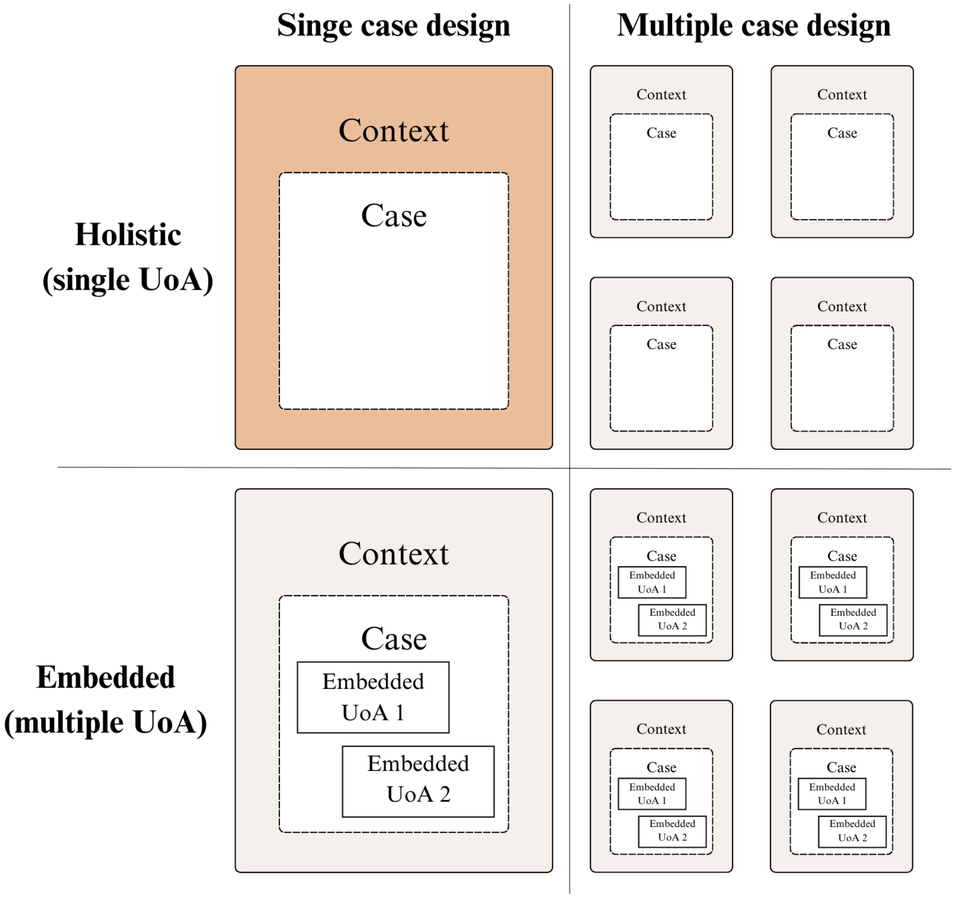

Figure 3.1. The four different types of case studies presented by Yin (2003). (Source: Own illustration based on Yin, 2003)

3.2 Research Design

After establishing the research strategy, a research design is developed, providing guidance for the study execution, data collection, and analysis. Instead of limiting the analysis to a more general discussion, solely based on theoretical gatherings, the study is designed to answer the research question through analysing a case company active in the Kenyan EV market and then evaluating the findings. Performing a case study allows for both quantitative and qualitative data collection in a real-world environment, as well as analyses and conclusions based on actual scenarios. Though the results are highly connected to the specifics of the studied case company, they are also applicable to other companies within the EV industry in Kenya and surrounding areas.

Case studies involve six key phases: planning, design, preparation, data gathering, analysis and reporting (Yin, 2003). The initial two stages are conducted iteratively with a supervisor from LTH and the case company, and establishes the thesis' purpose, research question, scope and project plan. The following phase, solely conducted by the thesis' authors, focuses on creating a theoretical framework and understanding the operational context of the case company. This is primarily done by conducting a profound literature review. Continuing, the data gathering and analysis phase includes expert interviews, qualitative as well as quantitative data analysis from the case company, and iteration of the literature review. During these phases, the aim is to gain enough information to address the research objectives and respond to the research question. In the final phase, results are shared continuously with LTH and the case company. Iterating this phase ensures ongoing validation of the relevance and validity of the analysis and conclusions. Additionally, workshops and discussions are conducted to directly engage the company, ensuring clarity and alignment with presented theory on successful implementation, as well as organisational goals.

The six phases of case studies presented by Yin (2003) can be translated into the problem-solving structure of the report, where data gathering represents empirics and reporting represents evaluation. *Figure 3.2* provides a concise overview of the research design, detailing six main elements, which are then further divided into activities. The figure also illustrates the iterative nature of the research design, through including dashed lines for both reviewing the theoretical framework based on empirical findings and receiving feedback from the case company and LTH, which is primarily conducted through meetings and discussions.

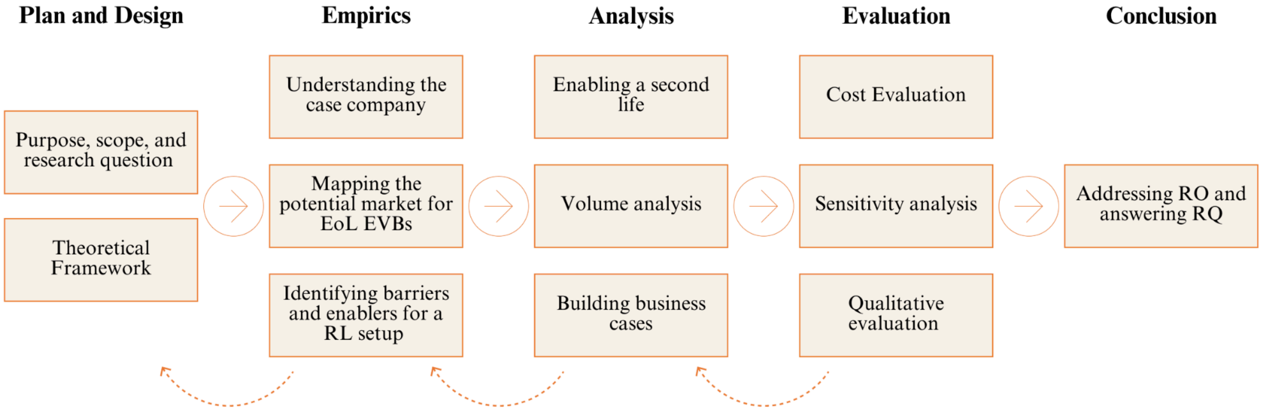

Figure 3.2. Overview of the research design.

3.2.1 Case Company

As the thesis aims to develop strategies enabling an efficient and sustainable handling of EoL EVBs in Kenya through implementing RL, Roam Electric, an electric mobility start-up founded in 2017, is a suitable case company. The company is based in the capital of Kenya, Nairobi, and is currently developing and assembling electric motorcycles, *Roam Airs*, for the local taxi market as well as corresponding hubs offering both charging infrastructure and battery rental. Additionally, though out of the scope of the thesis, Roam Electric is also developing and assembling electric buses for public transport, providing modular solar PV systems for both off- and on-grid applications using battery backup, and building customised software applications. As of now, Roam Electric is solely operating in Kenya but the ambition is to provide suitable electric transportation for greater parts of Africa, with the mission and ethos being "*Electrifying Africa one vehicle at the time"* and *"Made in Kenya, for Africa."* respectively. (Roam Electric, 2024)

3.2.2 Unit of Analysis

The UoA refers to the phenomenon or entity being studied, and can be defined as anything from an organisation, or part of an organisation, to an incident or an event (Fitzgerald and Dopson, 2009). Having a well defined UoA allows the researchers to address the defined purpose through providing guidance in investigating the research questions and objectives. The UoA for this single case study is *the reversed SC of EVBs, applied in the setting of Roam Electric.* Evaluating the problem from the case company's perspective allows for more realistic conclusions and recommendations in comparison to a more general analysis.

3.3 Data Gathering

Following the completion of the research design, the next phase involves the initiation of the data collection process. The data is collected through a combination of literature study, interviews, and study visits, with details explained below.

3.3.1 Literature Review

The theoretical framework, previously presented in *Figure 2.1*, serves as the foundation of the literature review. It involves studying academic journals related to EVBs, EoL handling of EVBs, SC theory, and the operating context of Roam Electric. The literature review is based on the three-step process described by Höst, Regnell and Runeson (2006, p. 67). During the initial step a broad search is made, which includes searching for a variety of keywords using *Google Scholar* and the *LUBsearch* database. To gain an overview of the three theoretical areas, searches using keywords and phrases such as "EVB life cycle", "battery value chain", "recycling EVB", "reverse logistics", "second life EVB applications", and "electrification Kenya" are made. The second step, evaluate and choose, includes skimming through the articles to narrow down the search, with the aim of retrieving relevant literature aligning with the purpose of the thesis. The final step of the process includes doing a deep search within the identified areas of relevance, meaning that these areas are further followed up.

Using the previously mentioned databases simplifies the process of finding peer reviewed articles, making up the foundation of the thesis. To retrieve articles within journals of relevance, such as *Journal of Environmental Management*, *Journal of Resources, Conservation and*

Recycling, and *Journal of Business Logistics*, sites such as *ScienceDirect* and *Emerald* are used. Peer reviewed articles are used with the purpose of ensuring quality of the information. However, this criterion is not followed in all occasions and data is collected from other sources as well, which is handled with extra caution by the authors. As the thesis advances, a deeper understanding of the scope is gained leading to further evolvement of the theoretical framework, and exploring new articles then becomes a prerequisite to proceed. This indicates that the three process steps presented by Höst, Regnell, and Runeson (2006, p.67) have to be performed several times, again highlighting the iterative process of writing the thesis.

3.3.2 Interviews

With the purpose of collecting both qualitative and quantitative data, 14 interviews, all shortly presented in *Table 3.1*, are conducted during the case study. The initial interviews focus on establishing a fundamental understanding of the thesis' scope and the case company, thereby limiting the range of the continued study. In addition to providing insight to the case company's strategy and potential of implementing RL, these interviews address questions aligned with the theoretical framework, mainly focusing on the market for EoL EVB handling in both Kenya and Europe. The initial interviews are then complemented with in-depth interviews, including more targeted and specific questions. As part of the in depth interviews conducted with representatives from the case company, the qualitative data is complemented with quantitative data in terms of, for instance, forecasted sales volumes and EVB life cycle estimations. To cover the entire scope of the thesis, interviews with representatives from the case company, experts within the Kenyan energy market, WEEE recyclers, and motorcycle distributors, among others, are conducted.

Table 3.1. Short presentation of all interviews.

Company	**Industry**	**Position**	**Language**	**Date**	**Length**
		Internal stakeholders			
Roam Electric	Electric mobility	Chief Operating Officer	English	2024-02-13	36 min
Roam Electric[D]	Electric mobility	Director of Battery Systems	English	2024-03-06	58 min
Roam Electric	Electric mobility	Co-founder and Director of Organisational Effectiveness	Swedish	2024-03-07	46 min
Roam Electric	Electric mobility	Product and Sustainability Strategist	Swedish	2024-03-07	42 min
Roam Electric	Electric mobility	Chief Product and Strategy Officer	Swedish	2024-03-08	59 min
Roam Electric	Electric mobility	Head of Energy and Charging Systems	English	2024-03-12	57 min
		Kenyan stakeholders			

Roam Electric; Company A	Electric mobility; WEEE recycling	Product and Sustainability Strategist, and Battery Engineer; Director	English	2024-02-15	29 min
Company A	WEEE recycling	Director	English	2024-02-15	42 min
Company B	Financial aid, Power Africa	Regional Energy Advisor	Swedish	2024-03-06	58 min
Company C[D]	Consulting and engineering within renewable energy	Chief Operating Officer	English	2024-03-13	25 min
Company D[D]	Financing	Managing Director of Company D Mobility	English	2024-03-15	31 min
European stakeholders					
Company E[D]	Green BESS	Co-founder and CEO	Swedish	2024-03-01	54 min
Company F[D]	Battery circularity	Founder and CEO	Swedish	2024-03-04	37 min
Company G[D]	LiB recycling	Senior Logistics Project Manager	English	2024-03-06	38 min
Company B	Financial aid, Power Africa	Regional Energy Advisor	Swedish	2024-03-06	58 min

[D] *The interview was performed digitally.*

Through being both targeted and insightful, interviews are considered one of the most important sources of evidence for case studies (Yin, 2018, pp. 157-161). However, interviews can also be biassed, due to either poorly formulated questions or response bias, or inaccurate, as a consequence of poor recall. To minimise these risks, open questions are formulated, stakeholders' own interests are taken into consideration, interviewees' responses to the same and similar questions are carefully compared, and most interviews are recorded. The interview questions are based on the established theoretical framework and are compiled in *Appendix A: Interview Guide*, which is structured based on the industry the interviewee operates within. Asking similar questions to all stakeholders within a certain area allows for a more trustworthy and accurate comparison and analysis of the answers. However, all interviews follow a semi-structured approach, meaning that they are adapted as the interview proceeds, allowing the interviewers to ask follow-up questions and for the interviewees to fully apply their take on the topic. Though an extensive literature review is conducted before going into the interviews, the Kenyan market is new to the authors and receiving local expertise and being able to ask on-the-spot questions is therefore highly valuable, motivating the semi-structured approach. This approach is further supported by Yin (2018, p. 161), who describes case study interviews as guided conversations with a quite fluid stream of questions pursuing the study's consistent line of inquiry.

3.3.3 Study Visits

In addition to spending two months at the case company, two stakeholders within e-waste recycling and repurposing are visited. The visits, shortly presented in *Table 3.2*, provide insight into the current work of the companies as well as their future plans. Through visiting the facilities and talking to representatives, a broader understanding of both barriers and enablers within the EoL EVB market in Kenya is given. Apart from the two organised study visits, the major Roam Hub is also visited. The purpose of the visit is to interact with the drivers and understand their perspective regarding potential EoL solutions of their Roam Air batteries.

Table 3.2. Short presentation of the study visits.

Company	***Industry***	***Position***	***Date***
Company A	WEEE recycling	Managing Director, Director	2024-03-04
Roam Hub Waiyaki Way	Battery Charging and Rental	Roam Air drivers	2024-03-13
Company H; Company I	WEEE Recycling; Battery Technology	Operation Associate; Battery Engineer	2024-03-14

3.4 Data Analysis and Evaluation

After establishing the data gathering methods, the data is structured before being further analysed and evaluated, adopting theory presented by Höst, Regnell and Runeson (2006, pp.114-116), Yin (2018, p. 212) and Miles, Huberman and Saldaña (2014). According to Miles, Huberman, and Saldaña (2014), data condensation, data display, and drawing and confirming conclusions are the three activity phases within the data analysis process. By performing the steps iteratively, the gathered information can be made clear and understandable. Data condensation involves simplifying and transforming data into a more comprehensive format to make drawing and verifying conclusions easier. This process includes writing summaries, coding, developing themes, and further refining the documentation for the final report, which overlap with some steps explained by Höst, Regnell and Runeson (2006, p.115), occurring continuously throughout data collection. Data display is the organised presentation of information that aids in drawing conclusions and understanding the data, and can be matrices, graphs, charts, networks, or plain text (Miles, Huberman and Saldaña, 2014). Lastly, drawing and verifying conclusions involves identifying patterns, trends, and explanations from the collected and displayed data to formulate final conclusions. These conclusions must be validated for their accuracy and reliability. In the thesis, these steps are combined and modified to make up the chapters empirics, data analysis and evaluation, all of which are further detailed below.

3.4.1 Empirics

Preceding the analysis of the data, the data collected through interviews and study visits is structured and presented in the *empirics*. Initially, based on internal interviews with Roam Electric, the focus lies on gaining an understanding of the case company including the corporate strategy, their EVB characteristics, and the current physical flows of the EVBs. This is to identify the prerequisites for handling EoL EVBs and to ensure that the potential proposed RL setup aligns with the overarching SC and corporate strategy. Secondly, potential markets for EoL EVBs in Kenya are mapped, considering repair, repurpose, and recycling. The final section entails mapping the barriers and enablers of RL, both in the European and Kenyan contexts. The collected data is summarised under various sub-chapter, following the data condensation process by Miles, Huberman and Saldaña (2014).

3.4.2 Analysis

The analysis chapter focuses on interpreting and drawing conclusions from the information gathered in the preceding chapter. To effectively implement a RL strategy, the initial analysis focuses on enabling a second life, including conclusions regarding the best suited second life application, determining who bears the responsibility for the EoL EVBs, the physical flows of collected EVBs, and the prerequisites the case company has to address the identified barriers and enablers of implementing a RL setup. Secondly, future volume estimations are analysed. This analysis is structured into two segments – estimating the future availability of EoL EVBs, and mapping the collection and EoL usability rates. The future availability estimation incorporates insights from expert interviews and internal data retrieved from the case company. Thereafter, second life business cases, carefully designed to cover various barriers and enablers of a RL setup and different aspects of the potential second life market for EVBs, are introduced.

3.4.3 Evaluation

As the purpose of the thesis is to, from a RL point of view, develop and evaluate actionable strategies enabling an efficient and sustainable EoL handling of EVBs in Kenya, the chapter following the analysis evaluates the presented business cases, rather than only discussing the result. The evaluation step of the data analysis involves comparing and evaluating the presented business cases, and thus validating the conclusions drawn in the analysis chapter, following the process by Miles, Huberman and Saldaña (2014). The evaluation takes several factors into account, including the economic viability for the case company, ease of implementation, and sustainability aspects. The aim is to determine whether the company can derive financial or strategic advantages from implementing a RL setup, including second life applications for their EoL batteries.

Going through the evaluating steps, the business cases are first evaluated on their financial performance. In this step, costs are added to the business cases presented in the previous chapter and these are then compared. Secondly, to ensure robustness and reliability of the evaluation process, a sensitivity analysis is conducted, allowing for a thorough examination of potential variations in key parameters. Thereafter, an overall qualitative analysis is conducted to evaluate aspects like implementation feasibility and sustainability, which can not be evaluated quantitatively.

3.5 Research Quality

When publishing a study, ensuring high research quality is essential. This chapter discusses the overall reliability and validity of the thesis, aligning with the criteria for judging the quality of research designs presented by Yin (2018, p. 78). *Figure 3.3* summarises the differences between reliability and validity with the preferred combination illustrated at the figure's far right.

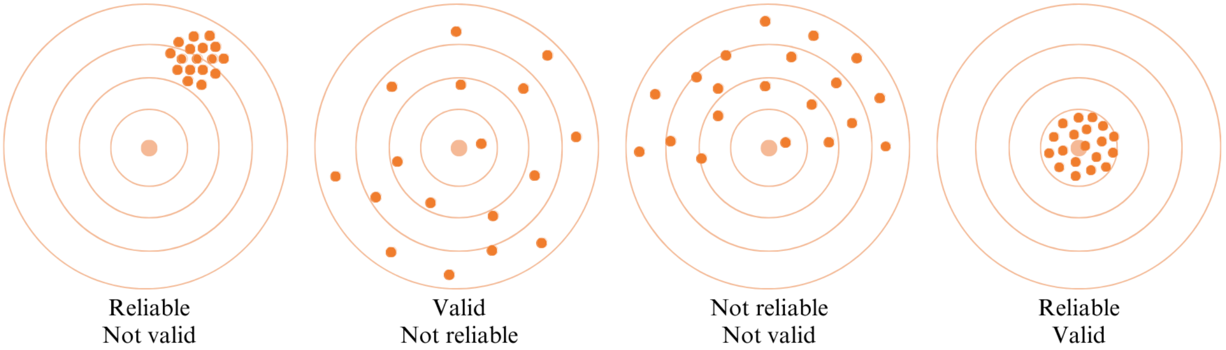

Figure 3.3. Illustration of the differences between reliability and validity.

3.5.1 Reliability

Achieving reliability means that a future investigator will make the same findings and draw the same conclusions when following the procedure presented by an earlier researcher and, hence, conducting the study again (Yin, 2018, p. 82; Robson and McCartan, 2016, p. 111). This essentially means that reliability is a way of measuring the method's accuracy over time and when performed by various researchers (Robson and McCartan, 2016, p. 19). Though repeating a case study is not frequently occuring, the performed procedures should anyways be carefully documented, allowing for repetition while ensuring accuracy and minimising biases within the study (Yin, 2018, p. 82). Robson and McCartan (2016, p. 173) further highlights the importance of not only being thorough, careful, and honest when carrying out the research, but being able to show others that you have been.

Yin (2018, p. 79) presents three methods for ensuring reliability of a study: using a case study protocol, developing a case study database and maintaining a chain of evidence. The case study protocol should include, but is not limited to, the following components: a case study overview, data collection procedures, specific data collection questions, and instructions for the case study report (Yin, 2018 p. 132). While the thesis does not have a formal protocol, all these sections are included to ensure reliability. Secondly, all evidence and information gathered, ranging from interview notes to field observations, as part of the empirical study is compiled distinct from the final case study report. Lastly, a chain of evidence is achieved through maintaining a red thread throughout the thesis by connecting the theoretical background to the empirical findings, and combining these in the analytical phase.

3.5.2 Validity

Validity refers to the accuracy of a study, ensuring that the data truly addresses the intended issue (Höst, Regnell and Runeson, 2006 p.109; Robson and McCartan, 2016, p. 19). Yin (2018, pp.

78-82) divides validity into three different categories: construct, internal and external validity, where construct and external validity are relevant for this thesis.

Construct validity is defined as *"identifying correct operational measures for the concepts being studied",* and is the most challenging test for a case study (Yin, 2018 pp. 78-80). The approach of ensuring and increasing construct validity includes using various sources, establishing a chain of evidence, and having key informants review the draft case study report. To ensure validity throughout the thesis, the results and analysis of the thesis are iteratively shared with the case company. Moreover, external validity assesses whether and how the findings of a case study can be generalised (Yin, 2018, p. 78; Robson and McCartan, 2016, p. 110). According to Yin (2018, p. 82) one approach to ensure external validity is to compare the results obtained from the case company with the outlined theoretical background. Due to the immature nature of the EV market in Kenya, theoretical findings from the European context and insights from European stakeholders are used as a point of reference, ensuring external validity.

One widely adopted strategy in academia to address various threats to validity and to enhance the robustness of a study, is to use triangulation (Robson and McCartan, 2016, p. 171). In this thesis, the following types of triangulation are used:

- Data triangulation: Interviews, observations, and academic journals are used for data collection.
- Observer triangulation: Two observers are used in the study.
- Theory triangulation: Multiple sources are used throughout the theoretical background.

3.6 Research Ethics and Social Aspects

According to the Swedish Research Council (2017), research ethics evolve dynamically. When new scientific questions, methods, or materials are introduced, new ethical challenges emerge. Since research plays a crucial role in today's society, high standards and quality are demanded of researchers. Researchers have a responsibility to both stakeholders directly involved and also to those impacted indirectly by their findings. Therefore, their research must not include any external influence or manipulation, and can not be built on personal, or specific stakeholders, interests. Researchers should strive for objectivity and avoid influencing research subjects or events. To prevent any bias, all sources in this thesis are correctly stated and the methodology is described in detail to ensure transparency. In addition, the study adhere to a handful of overarching principles stated by the Swedish Research Council:

1. You shall tell the truth about your research.
2. You shall consciously review and report the basic premises of your studies.
3. You shall openly account for your methods and results.
4. You shall openly account for your commercial interests and other associations.
5. You shall not make unauthorised use of the research results of others.
6. You shall keep your research organised, for example through documentation and filing.
7. You shall strive to conduct your research without doing harm to people, animals or the environment.
8. You shall be fair in your judgement of others' research.

Moreover, in the beginning of each interview the interviewees are informed of the purpose of the thesis and are not interviewed if no consent is given. Participants are also asked for consent to record the sessions and whether they prefer to be kept anonymous in the report or not. Additionally, the report is reviewed by the case company before publishing, to ensure protection of confidential information.

During the writing process, technological tools are occasionally used to help articulate and present the work in a more clear way. To achieve full transparency, the tools and their area of usage are presented in *Table 3.3*.

Table 3.3. Presentation of technological tools used during the writing process.

Tool	***Type of tool***	***Area of usage***
ChatGPT	Large language model	Grammar, rephrasing and sentence structuring
Google Translate	Translating service	Translating words between English and Swedish, and vice versa

4. Empirics

In the empirics, findings from the case company and other relevant stakeholders are presented. The initial part gives an in-depth understanding of the case company, focusing on their corporate strategy and current business model, EVB characteristics and logistical setup. Thereafter, the empirical data is used to map out potential markets for EoL EVBs in Kenya. Finally, identified barriers and enablers of implementing RL within both the European and Kenyan market are presented and, thereafter, compared.

4.1 Understanding the Case Company

Understanding the overall corporate strategy and business model, EVB characteristics, and current logistical flows of Roam Electric, further referred to as Roam, is essential for analysing potential RL setups for their EoL EVBs. To provide a clear understanding, a picture of the Roam Air is presented in *Figure 4.1*. The picture is taken outside one of the Roam hubs and shows two battery packs at the front of the vehicle.

Figure 4.1. Picture of the Roam Air with two battery packs. (Source: Roam, 2024)

4.1.1 Corporate Strategy and Business Model

To present the corporate strategy and business model of Roam, insights from several interviews with internal stakeholders are combined. Roam focuses on providing EVs that are to be used all day, every day. They therefore focus on motorcycles used for cargo and passenger transport, as well as buses for public transport. The reason for this is threefold, ranging from the impact these vehicles have for the people around them, in terms of reduction of air pollution, financial impact, and job creation, to the ease of setting up a charging infrastructure for predefined routes, and the rapid return of investment for the end user. Apart from planning to enter new markets in the coming years, Roam plans to aggressively increase their Kenyan motorcycle fleet, as indicated by their annual forecast of sold Roam Air's presented in *Figure 4.2*.

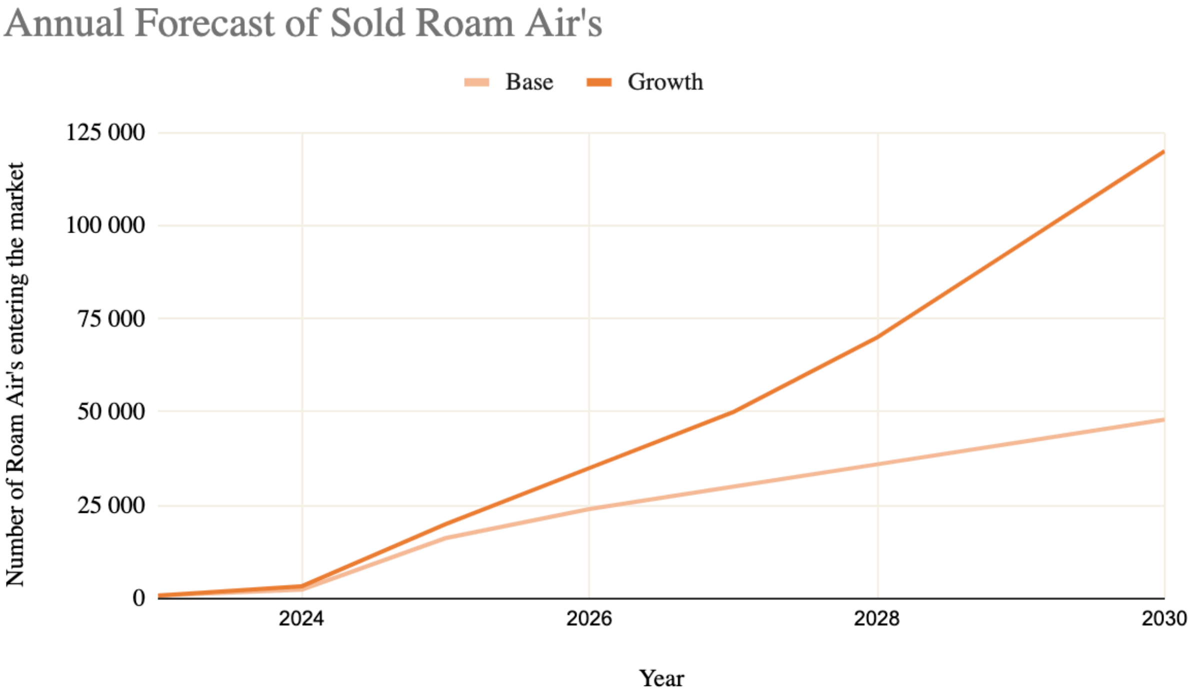

Figure 4.2. Expected number of Roam Air's entering the market in the coming years.

Roam has a customer-centric approach, with the goal of making the ownership of a Roam motorcycle, or Roam Air, as simple as possible, so that the owners can focus on running a profitable bodaboda business. To achieve this, and become a relevant player on the market, the Roam Airs are comparable to regular gasoline motorcycles from both a design and economic point of view. In regards to design, this ensures accessibility and widespread availability of spare parts, whereas it, in terms of economy, means to offer as low a price as possible, cutting costs, without compromising on quality, throughout the value chain. To make ownership economically viable for the end user, while minimising tied-up capital internally, Roam works with business-to-business customers, who then offer a lease to own payment model. For the motorcycle battery, the customer generally pays around 4% of the total battery purchase price upfront to the distributors and thereafter a small daily fee. Another factor that makes the Roam Air economically comparable to a gasoline motorcycle are the low running costs, where the cost of the electricity used per driven distance is less than the gasoline required for the same distance. Further aligned with their customer centric approach, the company offers a battery rental service to provide flexibility for the Roam Air owners.

With the basic idea of the company being to contribute to Kenyan electrification through locally changing the transportation system, sustainability is a core part of Roam's strategy. The main goal of the sustainability strategy is to get as many Roam Air's into the traffic as possible, and, in turn, contribute to decreasing the emissions caused by the motorcycle fleet. Currently, the company is working on further improving their sustainability strategy throughout the value chain, through, for instance, setting more strict sustainability requirements for their future batteries. On the other hand, these requirements need to be weighed against increased costs, which needs to be avoided to the greatest possible extent. The interpreted Roam Air business model is summarised in *Figure 4.3*.

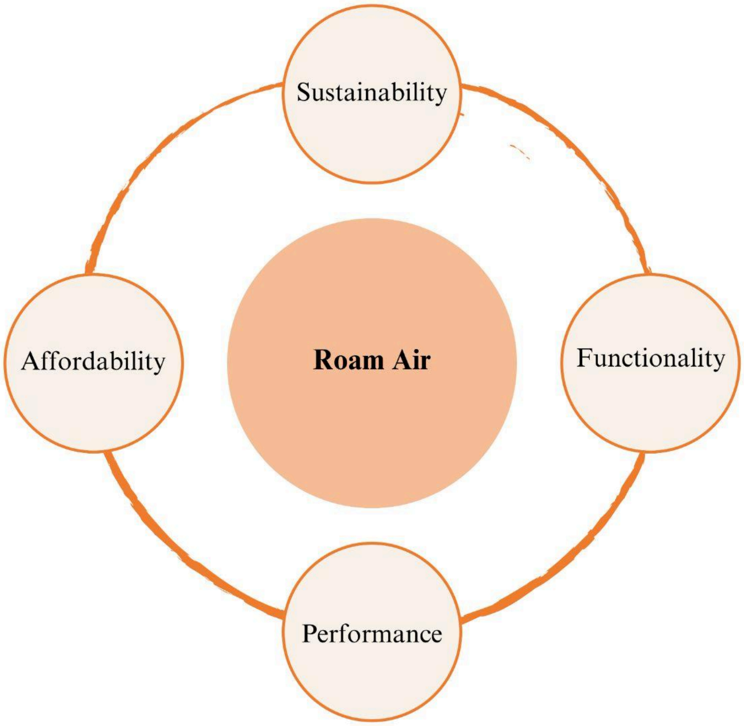

Figure 4.3. Summary of the interpreted Roam Air business model.

4.1.2 EVB Characteristics

The EVBs used by Roam are LiBs with a nickel based cathode, which, according to their COO, is because of their high energy density being a necessity to support the needs of a market characterised by heavy usage for multiple hours daily. One of Roam's battery engineers further states that such cells tend to have better rate capability and operating ability at high temperatures, in comparison to cells with other cathode active materials, which is suitable for the Kenyan market.

Roam are not manufacturing their own EVBs, but they decide on everything from the design of the battery to the features going into the cells and how they are assembled. According to their COO, a lot of time was spent on investigating the composition of materials within the cells as this varies greatly among suppliers. Acquiring the "right cell" is crucial for ensuring the desired performance. The cells used are 21700 cells, meaning that they are cylindrical with a diameter of 21 mm and a height of 70 mm. The cells are connected in series of 20, and one battery pack consists of a total of 180 cells. As presented in *Figure 4.4*, the cells are organised in two layers with nine times ten cells. With the purpose of stabilising the battery and minimising damage during the use phase, the battery pack is welded together. Each battery pack weighs around 20 kilograms, and has a maximum voltage and ampere hours of 80 and 72 respectively, resulting in approximately 3.2 kWh. When driving the motorcycle, one pack is used at the time.

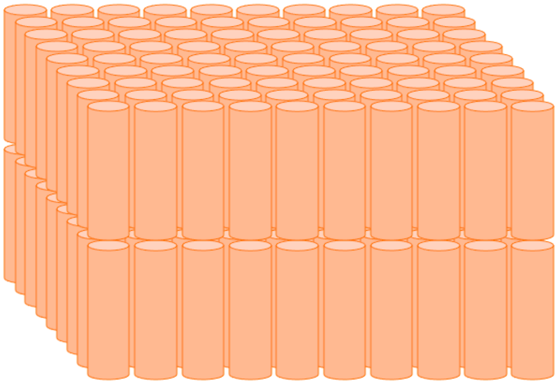

Figure 4.4. The pack structure of the Roam motorcycle EVBs.

As Roam is still in its early stages, the Roam Air's have not been on the roads for a long time. It is therefore not possible to calculate the average EVB lifespan based on real-life numbers, but internal estimations, using data provided by the BMS system, show that the expected lifespan is around two years. The BMS system provides Roam with information regarding voltages, currents, and temperatures, through data transmissions from the motorcycles every two minutes. Moreover, Roam is right now in the process of battery development with a dual focus on durability and serviceability in their new designs. Recognising the importance of sustainable practices, they are working on ensuring that their batteries are not only long-lasting but also designed for easy disassembly. In *chapter 5*, it is assumed that the future batteries will be dismantlable, a presumption made in collaboration with the company.

4.1.3 Mapping the Current Flows

This segment focuses on the logistical flows of Roam's EVBs, including sourcing, testing and storing, distribution, use phase, and returns. The insights lay a foundation for understanding how a RL setup can be designed to suit the current SC strategy. *Figure 4.5* illustrates the current flow of batteries within the case company.

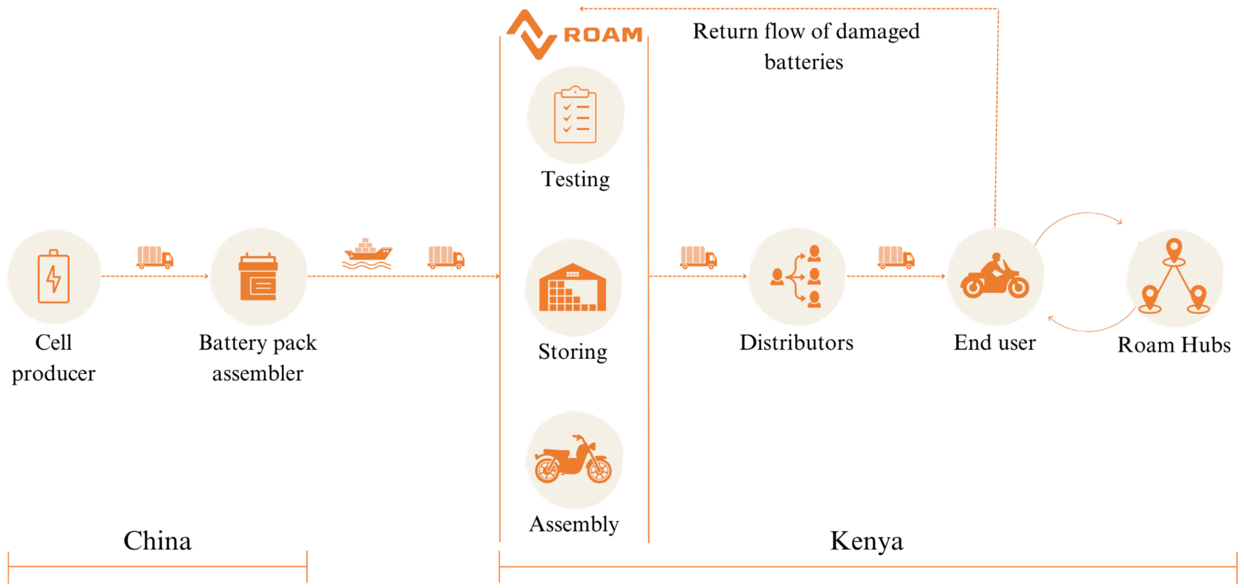

Figure 4.5. Process map illustrating the current flow of batteries for the case company.

Sourcing

Roam currently sources their batteries from China, procuring them from a single cell manufacturer with whom they have an established relationship. Apart from the previously mentioned material compositions, aspects like warranty conditions and minimising costs are of high importance, aligning the SC strategy with the corporate strategy of the company. The battery cells are then assembled into packs by a sub-assembler, also based in China. While Roam are actively seeking to diversify their supplier base and secure dual suppliers for most motorcycle components, the complex nature of the batteries complicates the process of finding a second supplier. Therefore, the company will continue to rely solely on one supplier, at least for the next few years.

Typically, there's a 30 day lead time from when an order is placed until the batteries can be shipped, and once they are ready it takes an additional 30 days for them to arrive in Kenya by ship. Roam orders batteries in quantities between 500 to 800 battery packs at a time, with the majority of orders falling around 500 to 600 units. According to the COO, it is a strategic decision not to order more or much less than a container's worth at a time, as the shipping cost per battery decreases as the container reaches its capacity. Since shipping a container costs around 3 000 USD, the shipping cost per battery is around 5 USD if 600 batteries are ordered.

Testing and Storing

Once the batteries arrive in Kenya and to Roam's facility, they undergo a thorough testing process. The testing process involves a full charge and discharge cycle to ensure their reliability and performance. Each battery gets connected to a telemetry unit, transmitting data to a database, and the batteries are validated to ensure that they can be safely used in the Roam Airs. Storing batteries is, according to the COO, a significant challenge for the company, not only due to their high cost, accounting for 40% of the bike's overall cost, but also because of the extended lead times involved in procurement. As the bikes can be built without the battery, due to the batteries being swappable, it is not necessary to have a high safety stock, especially when storing batteries require high upfront costs. Moreover, ensuring batteries are stored safely and meeting fire safety standards, adds to the cost burden and the logistical complexity. Given these challenges, the COO emphasises a preference for a Just-In-Time approach to the battery procurement, aiming to avoid the need for extensive storage facilities and mitigating associated costs as well as *"logistical headaches"*.

Distribution

The case company sells about one and a half batteries per Roam Air motorcycle. Each motorcycle comes with one battery, and roughly every other customer buys a spare one. As previously mentioned, Roam sells all their motorcycles to distributors who offer financing options to end customers. Currently, their largest distributor is Company D, a financial technology platform offering credit and digital financial services to underbanked consumers (Roam, 2023), with whom they have an ongoing partnership with. Company D has a 'Pay-As-You-Go' model where daily earners can acquire a motorbike immediately. The customers then gradually reach ownership through flexible micro-payments, extending between 18 to 24 months, making the motorcycles available for individuals without the financial means of an upfront payment. As of today, Company D constitutes about 80% of Roam's total sales but they are actively expanding their network to include other distributors as well. Looking ahead, Roam is envisioning a more balanced distribution landscape, with the aim of a 50/50 split between Company D and other distributors.

Use Phase

As explained in *chapter 2.3.3*, most two-wheelers are purchased for commercial purposes, primarily serving as taxis or for delivery services, which is also the case for Roam Airs. To accommodate the users, Roam provides both a charging at home solution, and a network of charging and battery rental hubs strategically located throughout Nairobi, ensuring that their riders can charge their EVBs during the day. As of 2024, there are four Roam Hubs operating, and all allow for both battery charging, of approximately 30 batteries simultaneously, and rental. The hubs allow customers to either pay to charge their batteries based on kWh consumption or rent a battery and pay for the swap. Roam's current estimations show that each hub can support around 300 batteries or bodabodas, which means that for every 300 motorcycles produced and delivered, another Roam Hub needs to be established. Their vision is to achieve full coverage of Nairobi, ensuring that riders never are more than five or 10 kilometres from a charging hub. Beyond that, they want to add more density to the regions with the highest use cases. This coverage approach aims to address range anxiety, allowing customers to navigate the entire city without running out of power. Additionally, there are ongoing initiatives to increase automation at these hubs, which are now managed by staff, to increase efficiency. By installing automated internet-connected charge points, the aim is to enable customers to plug in their batteries and initiate charging via mobile payment without the need of staff.

Return

The current return flows of Roam's EVBs involve the after-sales team receiving damaged batteries, which typically have issues with components like the connector, screen or handle. These batteries are taken to a dedicated battery lab within the Roam facility, where technicians assess and repair them accordingly. All of their current repairs are done on batteries that have yet not reached their EoL capacity and that only need a small fix before they are redistributed to the customers. For batteries that are reaching their EoL capacity, Roam explores internal use options, but as of now the number of spent batteries are relatively low. Though most batteries beyond repair are stored in the Roam facility, e-waste recyclers, promising a safe disposal, have been paid to handle a small fraction.

4.2 Potential Market for EoL EVBs in Kenya

Understanding the current Kenyan EoL EVB market, as well as getting insight in what direction it is heading, is vital when investigating potential EoL handling opportunities and their RL setups. To gain insight, interviews with Kenyan stakeholders, holding local market knowledge, are conducted and complemented with observational visits to stakeholders within Nairobi. The structure of the chapter is based on the three highlighted steps in *Figure 2.11,* presented in *chapter 2.4*, including: repair, repurpose, and recycle.

4.2.1 Repair

The first highlighted loop in the adapted CE model is about prolonging the initial lifespan of the batteries, and maintaining through repairing. For Roam, repairing the batteries means ensuring that their drivers submit the batteries for repair and that a repair service is available, either internally or at other repair service providers. Internal stakeholders emphasise the importance of having a functional repair process within Roam's facilities to ensure that batteries are handled in a safe manner. Moreover, as the repair stage addresses batteries that have not yet reached EoL in terms of capacity, interviewees within Roam and from Company A argue that drivers are incentivised to submit their batteries, considering that the batteries are an asset for their livelihood. For the screen and handles, there are spare parts and a possibility of repair. However, if the connector or anything in the pack would need even a minor repair, the whole battery needs to be changed. This is an example of how the current battery is not designed for circularity. As previously mentioned, there are plans to redesign the batteries, with the new ones having fully replaceable parts. This observation aligns with the presented theory in *chapter 2.2.1*, emphasising the importance of designing products with dismantling considerations in mind, a critical aspect of successful CE. As repairing is a part of prolonging the first life of the EVB and the purpose of the thesis concerns RL of EoL EVBs, this loop will not be further analysed.

4.2.2 Repurpose

The second highlighted loop in the adapted CE model involves repurposing the batteries that have reached a capacity that is too low for the motorcycles. According to the CEO and Co-founder of Company E, motorcycle batteries tend to degrade more rapidly than their counterparts in cars due to experiencing more intense wear and tear. If the batteries can be dismantled and tested, the cells within the packs can be combined in new ways to create new types of battery packs. There are also internal stakeholders who argue that the batteries could be combined already on pack-level, which would not require any dismantling. These repurposed battery packs have the potential to be marketed and sold as entirely new products, prolonging the batteries' lifespans, through giving them a second life, and maximising their value. In Kenya, various types of electronic waste are already repurposed and upcycled by private actors as well as the informal sector. This is noted by both internal stakeholders and by e-waste recyclers, who emphasise that minimal waste occurs within their market segment. They highlight that almost every item with inherent value undergoes repurposing and efficient utilisation. Due to the large size of the informal market, numerous individuals have gained expertise in refurbishing and repurposing items, such as batteries, at a low cost. However, e-waste recyclers point out that a significant challenge is that these remanufacturing activities pose a safety risk, as they involve hazardous materials and employ tools that are not suited for the intended task. Today, both Company A and Company H, the two visited WEEE recyclers in Nairobi, are repurposing battery packs previously used in solar home systems, which are easy to dismantle manually. Both companies highlight that the volume of EVBs is currently too low to develop an EoL management plan. Nonetheless, even though they are more difficult to dismantle, both companies are optimistic about finding second life applications for them when the volume increases.

"We are still looking for ways in which we can repurpose such batteries, but at least for solar batteries, we have a little bit of a solution for them, where we test them, then we make things like small energy storage systems, and lighting for the house, for the solar equipment." – Operations Associate, Company H.

The majority of the interviewed stakeholders, including actors within the Kenyan energy market, highlight the need of energy storage – to stabilise the energy grid, reduce the amount of renewable energy that goes to waste, provide backup power alternatives to diesel generators, and enable electricity access to more people, especially in rural areas. Several stakeholders also highlight the considerable costs associated with batteries for solar home systems and by finding environmentally sustainable ways to handle and repurpose EoL EVBs, energy needs of underserved regions can be addressed at lower cost.

According to the Regional Energy Advisor from Company B, investigating the possibility of using EoL EVBs for BESS is of great relevance, as there are various projects involving solar home systems and mini grids with the need of energy storage. However, he acknowledges that integrating EoL EVBs into traditional solar home systems may pose challenges due to the relatively large size of EVBs compared to the compact nature of typical solar home systems. Even though the Roam Air batteries are smaller than those used in electric cars, integrating them into a solar home system would be an ad hoc solution. Additionally, he believes that solar systems incorporating EoL EVBs cannot compete with the large-scale, low-cost production of standardised Chinese systems. He further explains that solar home systems are only a temporary solution and that expanding the electricity grid is crucial. Alternatively, the implementation of mini grids, supporting local communities and powered by renewable sources like solar, water, or wind, might also be a viable solution. In such projects, there is a demand for large-scale battery solutions, making it a relevant market for EoL EVBs.

"I would rather think that they would target mini-grid developers, and use those batteries for their systems, which are a little bit more large-scale." – Regional Energy Advisor, Company B.

This is also supported by the Head of Energy and Charging Systems at Roam, who perceives little potential for the batteries in small scale systems or for stabilising large grids. Instead, he identifies the primary market potential for Roam's EoL EVBs in rural areas where stakeholders are willing to invest in a system with an uncertain degradation rate, provided it is priced accordingly. According to the COO of Company C, a company providing consulting services within renewable energy, the two most promising use cases for EoL EVBs are mini grids and standalone systems for facilities, requiring BESS of around five kWh. In accordance with the theory outlined in *chapter 2.3.2*, he points out that electricity access is relatively advanced in Kenya, compared to other Sub-Saharan African countries, limiting the domestic market for mini grids.

4.2.3 Recycle

The final loop in the adapted CE model is recycling. Despite the recent rapid growth of the global battery recycling and the forecasted continuous increase in EoL EVB volumes, Kenya, and the African continent as a whole, currently lack recycling plants specifically dedicated to batteries. An important prerequisite for profitable recycling initiatives in Kenya, as highlighted by e-waste handlers, is the availability of large volumes of EoL EVBs. Therefore, players in the e-waste market reveal plans for establishing such facilities in the region within the coming years, answering to the forecasted EV market growth. As of now, e-waste recyclers are paid to handle various types of e-waste, which is also expected to be the case for EoL EVBs. However, the Director at Company A highlights that this may change as volumes and, hence, profitability of the recycling increases. This is also supported by the operating European battery recycler interviewed.

"Two or three years ago, there was something called a gate fee on the market, meaning that we were getting paid to get this material recycled. (...) Market is changing and we forecast that in a few years, there's not going to be a gate fee because we get money by selling the lithium and nickel or reusing it in our production, meaning buying less." – Senior Logistics Project Manager, Company G.

When setting up battery recycling plants in Africa, e-waste players can, according to interviewed stakeholders, get valuable insights from more established markets that have been at the forefront of developing recycling infrastructure for EVBs. During interviews with Company G, an European EVB recycler, they highlighted the challenge of being early adopters of new technologies, as this requires continuously addressing new obstacles and finding effective solutions. African players can address this challenge by adopting proven practices, as highlighted by the representative from Company H, who mentions learning from their European partners.

"But with time, we'll actually be able to process these things in our country. Because, you see, we are learning." – Operations Associate, Company H.

Even though there are currently no EVB recycling facilities in Kenya, both e-waste recyclers and internal stakeholders highlight the importance of recycling the batteries within the country. This is based on the will of using local labour, keeping the extracted material within the market, as well as avoiding the high costs and challenges of shipping EoL EVBs. As of now, the low received volumes of damaged or EoL EVBs are stored, awaiting a local recycling solution. However, some interviewed stakeholders argue that the recycling of EVBs will never be profitable in Kenya. The argument contradicts the interviewed European EVB recycler's experience, but, to some extent, it aligns with the theory presented in *chapter 2.1.1*, as research is taking place to reduce the material cost of LiBs and the profitability is highly dependent on the value of the retrieved materials.

4.3 Barriers and Enablers of RL for EoL EVBs

This chapter provides an overview of the barriers and enablers associated with implementing RL for EoL EVBs, as identified by interviewed stakeholders. To ensure a structured and systematic presentation of the data, the findings are categorised in accordance with the identified RL barriers based on studies from Waqas et al. (2018) and Azadnia, Onefrei, and Ghadimi (2021), outlined in *chapter 2.2.2*. Additionally, the chapter is divided into two sections: European and Kenyan context. The insights from European stakeholders serve as a valuable reference for understanding the EVB management of a more mature market. By comparing this to the Kenyan context, potential barriers and enablers in Kenya can be identified.

4.3.1 European Context

The identified *financial and economical related barriers* of implementing RL of EoL EVBs in Europe are the high investment costs of, among other things, establishing remanufacturing centres. Moreover, the high labour costs in Europe contribute to investors questioning economic viability, posing challenges in raising funds. Besides that repurposing and recycling of EoL EVBs involve emerging technologies and that many companies are still in the pilot stage, few stakeholders highlighted any *knowledge and experience related barriers*. Some frequently mentioned barriers fall under the category of *law and regulation related barriers*, highlighting that this category poses a significant barrier to implementing RL. The most influential barriers include the lack of clear regulations regarding import and export of EoL batteries, along with ambiguous policies on packaging and shipping.

"The whole import and export world is extremely grey. There is a big grey zone in Europe. There are still no rules on how to pack and ship (...)." – CEO, Company F.

Moreover, there is no clear definition of whether an EoL EVB should be defined as waste or a new product, leading to inconsistencies in shipping and handling procedures. This is also supported by previous research that states that labelling standards for EVBs pose a barrier for implementing RL. Both the Regional Energy Advisor at Company B and the CEO of Company F agree that the definition of EoL EVBs requires revision, highlighting the problematic nature of the current e-waste definition.

"There you would like, in a better world, to see these batteries as a resource and an asset." – Regional Energy Advisor, Company B.

"I think that it has to be much clearer on what is defined as waste. I personally don't believe in the definition of waste. No matter what, you can take care of it in some way. It's a product." – CEO, Company F.

Furthermore, regulations advocating for recycling are important to ensure that the current dirty battery production becomes greener, by mandating minimum levels of recycled content in batteries. However, regulations and policies that push for recycling might hinder the second life market, especially if these regulations are enforced before the EVB market is mature enough to support both markets. Additionally, the certification process for second life systems is currently time consuming and costly, which also hinders the market.

"I don't really believe in the European second life market today. It takes an enormous amount of time to certify a system. If you want to switch from one type of battery to another, it's very expensive." – CEO, Company F.

Nonetheless, stakeholders mention that there are several directives supporting the second life EVB market being introduced in the future.

"In Europe they are making it pretty easy for us. They are in the process of introducing the battery passport, where you will actually get some historical data. And then also some guidelines, rather than regulations for how to reuse. So, they have tried to introduce some actual rules for how batteries can be manufactured. (...) They've had to make it pretty vague, so we have a fairly free playing field that way." – Co-founder and CEO, Company E.

"I mean, in the EU, I think there will be directives or regulations saying that before you recycle it, you need to check whether it can be used for a second use, which in a way makes sense." – Senior Logistics Project Manager, Company G.

No *management and organisational related barriers* were mentioned during the interviews. However, several barriers within the *infrastructure and technology* category were highlighted. These barriers primarily revolve around the challenges associated with dismantling and matching cells, as they vary significantly. Additionally, determining the expected lifespan of second life applications and performance of repurposed battery systems emerged as a major concern within this category, affecting repurposers' bargaining power towards their potential customers.

"That is because all batteries look very different. And everyone has wanted to develop their own form factors, chemistries and such. So it's about being able to match them together in a good way. And keeping track of how they change will be a challenge in the long run." – Co-founder and CEO, Company E.

A key enabler to overcome this barrier is the advancement of test equipment, together with more available data, sophisticated BMSs, and battery passports. These technological innovations offer a more comprehensive understanding of the battery's first life cycle, allowing for better assessment and decision making. For instance, new portable technical testing solutions capable of assessing various aspects to determine the full SoH, are mentioned in interviews. Another overarching *technology related barrier* is the fact that all technologies for EoL handling of EVBs are new, and it takes time to get a business model to work.

"Everything is to be established in terms of type of agreement, type of partnership, part of the logistics and the actual scaled up technology. " – Senior Logistics Project Manager, Company G.

In terms of *infrastructure related barriers,* one main logistical challenge is to determine the location and destination of EoL EVBs. The logistics of collecting and transporting batteries are relatively straightforward, but determining the most appropriate course of action is both crucial and complex, as there is not a single designated destination for all batteries. An enabler for determining who bears the responsibility of the EVBs and thus the course of action is EPR, presented in *chapter 2.1.2.* However in a CE, all participants act as both consumers and producers, making the EPR regulation complex, according to Cling Systems (2023). Company F argues that efficient transfer of responsibilities among players in the market is important for promoting circularity. This involves managing three essential components when trading EoL EVBs: *Possession, Responsibility* and *Ownership.* They explain that to transfer possession, batteries require transportation. To transfer responsibility, participants need EPR release forms and to transfer ownership, participants must agree on a price for purchasing used EVBs.

Regarding *environmental*, and *market and social related barriers*, few are mentioned except that the market is still very new and thus unpredictable. However, stakeholders emphasise the strong environmental consciousness in Europe, contributing to the emergence of both repurposing and recycling markets. Furthermore, social pressure, in terms of both environmental and ethical sourcing, is put on manufacturers as well as end users, strengthening the business case of EoL handlers within Europe. This is also reflected in policies as no *policy related barriers* are mentioned by interviewed stakeholders.

4.3.2 Kenyan Context

In terms of *financial & economical related barriers*, stakeholders operating within the Kenyan market highlight a few. Initially, the investment costs of both battery testing equipment – essential for enabling a second life – and recycling facilities are significant. For instance, the representative from Company H mentions that they are planning on setting up a battery recycling facility, but to do so they need to raise enough funds. The representative from Company B also highlights that raising funds for second life applications, with an uncertain lifespan, can be challenging. As mentioned in *chapter 4.2.3*, another identified financial barrier for recycling is the current EVB volumes being too low to make it economically sustainable. In regards to second life applications, several stakeholders mention that these systems have to compete with the mass-produced ones imported from China. Keeping down the costs of rebuilding and redistributing the batteries is therefore crucial, where the low labour costs in Kenya increase the market's competitiveness through enabling solutions, such as manually separating battery cells, that are not economically viable within the European market.

The Managing Director of Company D mentions that their customers' interests are primarily economic. Saying this, he emphasises the risk of drivers using or storing their batteries when they are no longer considered safe, which can be seen as a *knowledge and experience related barrier* for EoL handling of EVBs. The Operation Associate from Company H mentions that they work a lot with educating people about e-waste in general and making sure that EoL information is available, with the purpose of increasing the amount that is properly disposed of. However, there is consensus that awareness of environmental impact and safety risks posed by EoL EVBs is not enough, and all interviewed stakeholders agree that some kind of economic incentive, for instance a cash-back or discount on a new product, is essential in the collection phase.

"There is a lot of talk about the circular economy. And I think, comparatively, the African economy is quite circular. You have limited resources, you take care of everything. There is potential value and profit. (...) As long as there are financial incentives, everything will work." – Regional Energy Advisor, Company B.

"I mean, it's going to have to come down to the financial incentive. There has to be a financial incentive to do this." – Battery Expert, Roam Electric.

When visiting one of the Roam Hubs in Nairobi and interacting with the Roam Air drivers, the hypothesis regarding economic incentives was confirmed. A couple of drivers had not yet considered what to do at EoL as their motorcycles were still so new, whereas others had clear ideas. One driver mentioned that he would sell it back to Roam *"as that is how it works with batteries"*. Several drivers pointed out that the batteries are very expensive, where one mentioned selling it to the informal sector if possible and another one stated that he would only consider buying a new one if the price is comparable to buying a regular gasoline engine for the motorcycle. Others mentioned that they expected a 20-30% discount on their new batteries when returning their current ones, whereas a few were just determined to buy a new battery and did not expect anything in return.

In regards to *law and regulation related barriers*, the main concerns revolve around the existence of laws but lack of effective enforcement mechanisms, alongside insufficient governmental policies supporting RL for EoL EVBs. Instead, e-waste handlers need to deal with requirements of unclear licence applicable for household waste. It is also mentioned that licences for, for instance, transporting waste are distributed by the National Environment Management Authority, but that finding out what licences are applicable for your business is problematic.

"We require the companies to comply with the legislation that exists in the country. But you don't get very far with that because there is no one who enforces the law. (...) There are too weak institutions, there is too much corruption." – Regional Energy Advisor, Company B.

"So there are laws in place, but because of insufficient enforcement and lack of accountability, they are not being followed." – Product and Sustainability Strategist, Roam Electric.

"One of the biggest challenges in the country is that you don't know until some guy rocks up and says, 'you should have this'. You can't even find it out." – Managing Director, Company A.

Moreover, Kenya has signed the Basel Convention, presented in *chapter 2.3.4,* with the purpose of regulating the import of waste. However, this hinders the potential of regional recycling processes as no e-waste can be transported across East African borders. If the convention is not adopted, this would, in turn, mean that all countries in the region would need their own repurposing and recycling plants to avoid shipments outside of the continent, according to Company A.

"So you want to be doing as much as you can as close to the problem as possible, that's the first thing. You don't want to be shipping this stuff across the border for stock because even in East Africa, forget about it. (...) We could have used East African labour, we could have recycled all the metal here, we could have stopped all the logistics going back to Dubai, we could have just shipped it from Uganda to Kenya, but because we signed up to the Basel Convention, we say we will not accept cross-border e-waste. So we've taken what was a good idea to stop dumping in Africa and we implemented it in such a way that it stops us from processing in Africa." – Managing Director, Company A.

As the case company is engaged in setting up RL practises, no *management and organisational related barriers* are identified. However, several external stakeholders mention that the business model Roam is using, where the batteries are sold to the final customer instead of solely included in a swapping system, may make RL more challenging. It is argued that a swapping system allows for more simple EoL handling, through mitigating the hurdle of locating and buying back the batteries. According to the Director at Company A, one of the major challenges of getting e-waste back to repurposing or recycling centres is logistical, falling under the category of *infrastructure and technology related barriers*. In Kenya, any consumer electronics that stop working or significantly lose capacity, and are not under a warranty with return schemes, tend to end up dying in the field.

"I don't even think it ends up in landfills, I think it just ends up lying around doing nothing." – Director, Company A

The Director of Company A emphasises that this is a big concern regarding the handling of EoL EVB as well, as if the battery, which is the major component of the motorcycle, is not functioning properly the motorcycle will most likely be dumped. He fears that once the Roam batteries have lost capacity and are out of their 'Pay-As-You-Go' period, they will not find their way back to Roam, a distributor, or a recycler as easily as malfunctioning, relatively new batteries do today. Avoiding this, and making sure that a larger part of electronics ends up as formal e-waste at EoL, comes down to increased awareness and education, developed infrastructure and receiving networks, incentives, and even ease.

The EVBs currently present on the Kenyan market are not designed for circularity, classifying as a *technology related barrier*. For instance, the Roam Air battery packs are welded, complicating the process of manual dismantling and posing risks of potential harm to the cells. Moreover, the lack of cell standardisation is a barrier to circularity, as repurposed packs must be constructed from the same type of cells. Not requiring circular design of EVBs could also be considered an *environmental related barrier*. Apart from that, no specific ones are identified. However, as previously mentioned, several laws, including environmental ones, are not effectively enforced. Similar to the European context, challenges regarding the uncertain performance of second life systems make it difficult to accurately predict their lifespan. Consequently, this uncertainty limits the potential market for such systems.

Compared to the European market, the Kenyan market does not possess the same level of community pressure in regards to sustainability, which is considered a *market and social related barrier*. Other identified barriers are the uncertainties in potential demand of EoL EVBs, the expected quantity of return, and the expected volume which can be recovered and used for a second application. Finally, no barriers within the category *policy related barriers* are identified during the interview study.

4.3.3 Summary

Table 4.1 summarises all barriers related to RL of EoL EVBs identified by European and Kenyan stakeholders respectively. As seen on the right hand side of the table, many barriers are common for both markets, even though they originate from different reasons and affect the markets to various extents. The majority barriers are within the categories *financial and economical*, *law and regulation*, and *infrastructure and technology*, while *environmental* and *policy* are not included at all. However, it is important to note that the results presented in the table are based on interpretations from a limited number of interviews and study visits, indicating that further similarities and differences exist.

Tabel 4.1. Summary of barriers of successful RL implementation for EoL EVBs, identified by European and Kenyan stakeholders.

Barriers	Europe	Kenya
Financial & Economical Related Barriers		
High investment costs	X	X
Challenges in raising funds	X	X
High labour costs	X	
Low EVB volumes		X
Compete with mass production		X
Knowledge & Experience Related Barriers		
New technology	X	
Low knowledge regarding safety aspects		X
Law & Regulation Related Barriers		
Lack of clear regulations regarding import and export	X	
Ambiguous policies on packaging and shipping	X	
Insufficient definition of EoL EVBs	X	X
Regulations pushing for recycling, hindering second life applications	X	
Lack of effective enforcement mechanisms		X
Insufficient governmental policies supporting RL		X
Agreements hindering regional EoL handling		X
Management & Organisational Related Barriers		
Batteries owned by end users		X
Infrastructure & Technology Related Barriers		
Lack of standardisation	X	X
Uncertain lifespan and performance of second life applications	X	X
New technology	X	

Determining the destination of the EoL EVB	X	
Locating the EoL EVB	X	X
Not designed for circularity		X
Market & Social Related Barriers		
Emerging and unpredictable market	X	
Lack of community pressure in regards to sustainability		X
Uncertain demand for second life applications		X
Encertain quantity of returned EoL EVBs		X
Uncertain quality of EoL EVBs		X

As barriers and enablers are highly correlated, it is possible to identify several enablers based on the barriers presented in *Table 4.1*. For instance, a barrier mentioned by both European and Kenyan stakeholders is the challenges in raising funds, making funding an easily identified enabler. Apart from the enablers that can be directly drawn from the barriers, the stakeholders mentioned additional ones during the interviews. The enablers, or prerequisites of successful RL implementation, that were directly mentioned during the empirical studies are summarised in *Table 4.2*. Differentiating the two markets is the high trust in regulations and environmental consciousness characterising the European market, in contrast to the economically driven Kenyan market, where financial incentives are frequently mentioned.

Table 4.2. Summary of enablers of successful RL implementation for EoL EVBs, identified by European and Kenyan stakeholders.

Enablers	***Europe***	***Kenya***
Advancement of testing equipment	X	X
Battery passports	X	
Development of infrastructure, including a receiving network		X
Ease		X
Economic incentives		X
Education regarding environmental sustainability		X
Environmental consciousness	X	
EPR and CSR	X	
Increased data availability	X	X
Information flows regarding EoL handling		X
Low labour costs		X
Regulations advocating for repurposing and, in turn, recycling	X	
Swapping systems		X

5. Analysis

Building on the empirics, this chapter combines empirical findings with presented theory to analyse the potential for implementing a second life cycle for Roam's EoL EVBs. Initially, the requirements for enabling a second life are determined, considering a suitable second life application, EoL responsibilities, collection routes, and case company prerequisites. Subsequently, future volumes of EoL EVBs are estimated with the purpose of understanding the scale of potential opportunities. Finally, the combination of the empirical findings and the analysis results in the development of three separate business cases. The cases represent potential future scenarios and approaches to implementing a second life strategy for the EoL EVBs, which are then further evaluated in chapter 6.

5.1 Enabling a Second Life

As highlighted in the empirics, the initial step in establishing a RL setup involves determining the most appropriate course of action, considering the diverse destinations for the batteries. Next, it is crucial to identify the responsible parties for handling EoL EVBs, along with ownership and possession. Finally, the physical return flow needs to be established, including implementing incentives for collection, establishing collecting hubs, and defining collection routes. The chapter concludes with a discussion regarding the company's opportunities to address the barriers and enablers presented in *chapter 4.3*.

5.1.1 End-of-Life Applications

The chosen EoL application for Roam is BESS for mini grids or standalone systems, requiring a BESS of around five kWh. This strategic decision aligns with the theory presented in *chapter 2.2.1*, highlighting BESS as the most prevalent and economically viable second life application. Moreover, insights from the empirics indicate needs of the Kenyan energy market, emphasising the demand for reliable and sustainable energy solutions. Reflecting on the theory presented in *chapter 2.3.2*, and as mentioned by interviewees, Kenya has a relatively advanced electricity access, compared to other Sub-Saharan African nations. This could limit the Kenyan demand for *mini grids*, while simultaneously indicating that deploying in mini grids might be more effective in areas with less developed electrical infrastructure, as in Kenya's neighbouring countries. Additionally, this also aligns with Roam's expansion strategy targeting these countries. However, as presented in theory, 80% of Kenyan companies experience frequent power outages. As most PV systems without a BESS disconnect from the grid during these outages, there is a need for standalone systems for companies. Notably, a majority of the interviewed stakeholders highlight the critical need for energy storage, with the purpose of:

- Stabilising the energy grid to ensure consistent and reliable power supply
- Reducing the amount of renewable energy that goes to waste by efficiently storing excess energy for later use
- Providing backup power alternatives to diesel generators, promoting cleaner and more sustainable energy options
- Enabling electricity access to more people, especially in underserved rural areas

By repurposing the EoL EVBs into BESS, the potential is that Roam can address these needs effectively while maximising the economic value of the batteries. Moreover, a second life strategy aligns with the sustainable core of the company, contributing to their overall green image.

5.1.2 Determining Responsibility

An enabler for determining who bears the responsibility for the EoL EVBs and therefore the course of action and logistical planning, is EPR, presented in *chapter 2.1.2* and further discussed in the empirics under *chapter 4.3.1*. However, while EPR is an enabler for RL in Europe, both theory and insights from the empirics conclude that implementing EPR can be particularly challenging in countries like Kenya, where legal enforcement is lacking, posing a significant barrier to compliance. Despite the limited enforcement of EPR laws in Kenya, Roam is dedicated to adhere to regulations, thus assuming responsibility for managing their EoL EVBs. Moreover, as mentioned in *chapter 4.1.1* Roam wants to further improve their sustainability strategy including stricter requirements for their future batteries and a EoL strategy. By adhering to EPR laws, they also ensure that their EoL EVBs do not end up on one of the poorly managed dumpsites existing in Kenya mitigating the risks presented in *chapter 2.3.5*.

Transferring roles of responsibility, ownership, and possession when trading EoL EVBs becomes particularly challenging in Kenya, both due to the limited governance enforcement but also lacking community pressure and environmental awareness, compared to Europe. Moreover, identified as an enabler for EoL management is a swap system which, as mentioned, would mean that Roam would have both responsibility and ownership of all their batteries. As this is not their business model, clearly defining the roles is of utmost importance. Regarding ownership, batteries are typically owned by drivers, distributors, or Roam in rental scenarios and as previously mentioned, to transfer ownership an appropriate price needs to be determined. On the other hand, possession is typically held by drivers or hubs and requires transportation to be transferred.

5.1.3 Physical Flows of Collecting EoL EVBs

In terms of collection processes, there is a dual requirement for both physical and economic transfers. Physical transfer implies the exchange of possession, while economic transfer enables the transfer of ownership. Ensuring the collection of EoL EVBs, thus preventing them from ending up dying in the field or falling into the hands of the informal sector, is identified as a significant barrier in the empirics. However, economic incentives emerge as a crucial enabler in addressing this challenge. While environmental awareness and governmental policies supporting RL are key enablers in Europe, nothing is considered as important as economic incentives for the Kenyan market. Recognising the economic considerations at play, stakeholders highlight the need for tangible benefits or rewards to motivate owners in participating in the EoL EVB collection process. These include payment for the old battery or receiving a discount when buying a new one. Out of these, the last mentioned is deemed most appropriate as it serves as an incentive for riders to acquire another battery, thereby extending the usage of their motorcycle. This not only generates revenue for Roam but also aligns with their objective of electrifying the vehicle fleet in Kenya. Furthermore, given the theory presented in *chapter 2.2.3*, the incentives need to be properly aligned to mitigate the risk of SC discomfort. Discussions regarding an appropriate discount focuses on finding the optimal balance of action from the battery owners and profitability for the case company. A discount of around 20-30% has been mentioned by Roam Air drivers, and is seen as substantial enough buyback to motivate action. However, this number is very high in comparison to presented theory on trade-in systems within the home electronics industry, and needs to be validated to be considered reasonable.

Once the incentives are aligned, the next crucial step in implementing RL for the EoL EVBs involves establishing an efficient physical route for their EoL handling process. Initially, the location of the EoL EVBs needs to be identified. Although Roam has data on where the motorcycles are located, there is no specific tracking of the individual batteries. Consequently, the focus returns to properly aligned economic incentives, being critical in ensuring that the batteries are directed towards the designated collection route.

As noted in *chapter 2.2.2*, the lack of efficient collection sites is a major barrier to implementing RL. This is further emphasised in *chapter 2.3.4* as enabling infrastructure is presented as a critical factor for Kenya to fully embrace the development of the EV industry. Kenyan stakeholders also highlight this in *chapter 4.3.2*, discussing that developed infrastructure and receiving networks are essential enablers for ensuring that e-waste is directed into formal channels. Despite Roam not having a plan to construct new collection points specifically for their batteries, an innovative approach to address this is to utilise already existing infrastructure, like the Roam Hubs, for this purpose.

These Roam Hubs could serve as convenient locations where battery owners, especially end users, can return their EoL batteries, get their discount code, and then rent a new battery, thus ensuring uninterrupted service. Turning the hubs into collection points offers a dual benefit – it streamlines the collection process for Roam while providing an easy return process for the battery owners. With four hubs already operating within Nairobi and several more to come, *as presented in chapter 4.1.3*, Roam can effectively leverage the already existing network. Moreover, installing testing equipment at the hubs would be an efficient solution for decision making regarding repurposing or direct recycling of the returned EoL EVBs. This approach further streamlines the EoL EVB management process by minimising the need for transportation and situating the decision making to the point of collection. If no testing equipment can be made available at the hubs, the approach would include collecting all batteries and transporting them to a centralised facility, like the Roam factory, for testing and evaluation. This must include safe storage, which would add to the logistical complexity discussed in *chapter 4.1.3*. The EoL EVBs that are deemed suitable for repurposing are, in turn, rebuilt onsite. *Figure 5.1* illustrates the process flow.

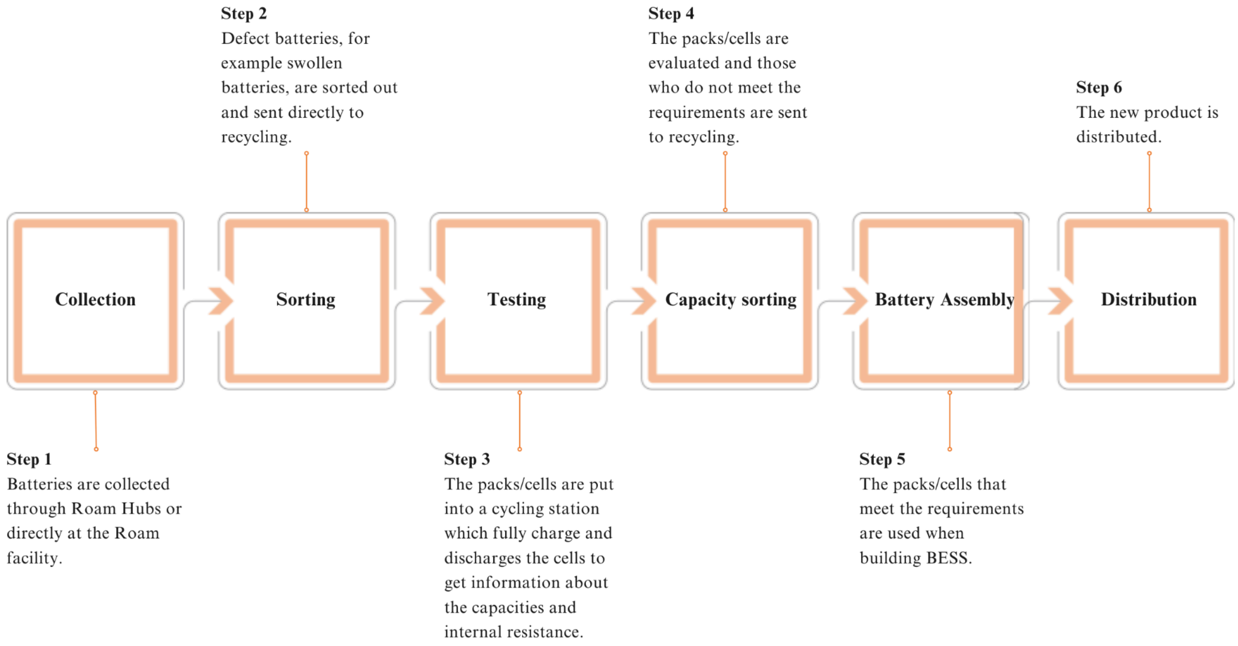

Figure 5.1. Proposed RL process flow.

5.1.4 Case Company Prerequisites

Based on *chapter 4.3*, where barriers and enablers of implementing RL for EoL EVBs are identified, details regarding the company outlined in *chapter 4.1,* and theory on successful implementation, presented in *chapter 2.2.3*, the current prerequisites and areas of development for Roam are identified.

To successfully implement RL and EoL handling processes, it is crucial to address the identified barriers and integrate enabling factors. The barriers identified in the empirics align well with the theoretical ones presented in *chapter 2.2.2*. As one significant barrier is *determining the destination of the EoL EVB*, deciding to produce BESS is the first main step in addressing that. Additionally, Roam's established energy department, which provides modular solutions for both off- and on-grid applications using battery backup, offers an opportunity to seamlessly integrate EoL EVBs into its existing business. This allows Roam to leverage its already existing market presence and product knowledge. Enabling factors include *development of infrastructure*, like a receiving network, and ensuring an easy return process. Using existing infrastructure, such as Roam Hubs, simplifies returns without requiring extensive infrastructure investments. This approach also aligns with SCND theory presented in *chapter 2.2.3*, as the configuration of the nodes involved in the receiving and returning network already are strategically allocated to meet customer demand for nearby charging opportunities. This also addresses the challenge of *locating the batteries* as the drivers are incorporated in the RL setup. To properly address the barrier, it is essential to have clear communication with customers about EoL handling procedures, especially without a swapping system, ensuring smooth battery ownership transfers.

Increased data availability is mentioned as an enabler to address the barrier of *uncertain quality of EoL EVBs*. With Roam's extensive software team, they have prerequisites to be able to handle the data, the software team just need to be involved in strategy setup to leverage their expertise. This is also important to address the challenge presented by Sheikh et al. (2022) in *chapter 2.1.1*, stating that the primary technological challenge when repurposing EVBs is to create a BMS adapted to the new system. Furthermore, as mentioned during interviews, social and ethical policies are relatively prominent in Europe with many companies placing great emphasis on CSR, aligned with theory presented in *chapter 2.1.2*. Since environmental sustainability awareness is an enabler on a more mature market, integrating that into customer communication and information flow could enhance the effectiveness of EoL strategies, even on the emerging Kenyan market. Roam's strong commitment to sustainability acts as an additional enabler, increasing the likelihood of successfully implementing RL and a second life strategy.

Besides the necessary physical requirements for successful implementation of RL, organisational prerequisites are also important. These prerequisites tie back to the discussion in *chapter 2.2.3* regarding the keys to successful implementation. Even though implementing RL is not a modification to existing processes, it represents a significant SC transformation project, altering traditional SC setups. To manage this transformation. effectively, the five critical success factors of change management offer valuable guidance:

- Executives commitment and visible support
- Comprehensive supply chain strategy
- Articulation case for change
- Proven change management methodology
- Maintaining energy and involvement

Leadership endorsement is crucial to set the tone for the entire organisation and ensure alignment with the RL initiative, and as discussed in *chapter 2.2.3*, only 30% of SC transformation projects succeed, with ineffective management of people aspects being one reason. Secondly, a well-defined strategy is necessary to integrate RL seamlessly into existing processes and align it with broader business objectives. Continuously, clear communication about the rationale behind RL implementation is essential to get buy-in from stakeholders and gain support throughout the organisation and by communicating both sustainability aspects as well as a profitability analysis, this can be achieved. Employing a structured approach to change management ensures that the implementation of RL is well-planned, efficiently executed, and sustained over time. Lastly, keeping the engagement and involvement from stakeholders are crucial to prevent resistance and ensure the successful adoption of RL. This could, for instance, be investors that want to see results, or end customers who could benefit from a reminder of the advantages of returning their batteries at EoL.

5.2 Volume Analysis of EoL EVBs

Given that the economic viability of different EoL solutions depends on the available volume of EoL EVBs on the market, performing a volume analysis is crucial for developing an actionable and efficient strategy for the case company. This chapter uses projected market availability of EoL Roam Air EVBs, alongside anticipated collection rates and battery usability, to finally estimate the available volume for building BESS.

5.2.1 Market Availability

The available volume of EoL EVBs directly correlates with the market volume of EVBs, why forecasted sales volumes of Roam Air's, and hence, sold EVBs can be used to estimate the EoL EVB market size. One barrier with implementing RL, according to theory, is inaccurate forecasting, which is important to keep in mind when analysing the retrieved values. However, the novelty and uncertainty of the market makes it difficult to make accurate estimations. Using forecasts and calculations from the case company as well as knowledge of EVB lifespans, gained from the theoretical background, rough estimations of the EoL EVB market can be made.

As outlined in the theoretical background, EVBs typically last between 8-10 years, but their lifespan is highly affected by the use phase. The presented lifespan is also based on batteries used in cars, which may not directly apply to motorcycle batteries. Information gained through the empirical studies indicate that motorcycle EVBs have a significantly shorter expected lifespan, due to both their smaller size as well as their exposure to more rough cycling. Calculations made by Roam, taking the high operating temperatures in Kenya into consideration, suggest that the expected lifetime of their batteries is around two years. However, accounting for the high usage of the Roam Airs, with multiple expected daily cycles on poor roads, and the Kenyan market's inclination of maximise product capacity, the lifespans presented in *Table 5.1* are used. These assumptions are made in coherence with Roam's Director of Battery Systems and their Head of Energy and Charging Systems.

Table 5.1. Expected lifetime of the Roam Air EVBs.

Lifetime (years)	***Share of batteries (%)***
1	10
2	70
3	20

To estimate the EoL EVB volumes, it is, based on EPR theory and the need for cell standardisation, assumed that Roam is responsible for their own battery collection. Furthermore, it is estimated that two batteries will be sold per motorcycle, accounting for 1.5 sales per motorcycle and extra units for the rental service. Considering the expected EVB lifetime, presented in *Table 5.1*, as well as the base and growth forecasts of annual Roam Air sales, presented in *Figure 4.1* in *chapter 4.1.1*, the estimated number of batteries reaching EoL are calculated. The forecasted estimation of EoL batteries on the market is presented in *Figure 5.2*. As seen in the graph, the volumes range between around 71 000 to 137 000 battery packs by 2030.

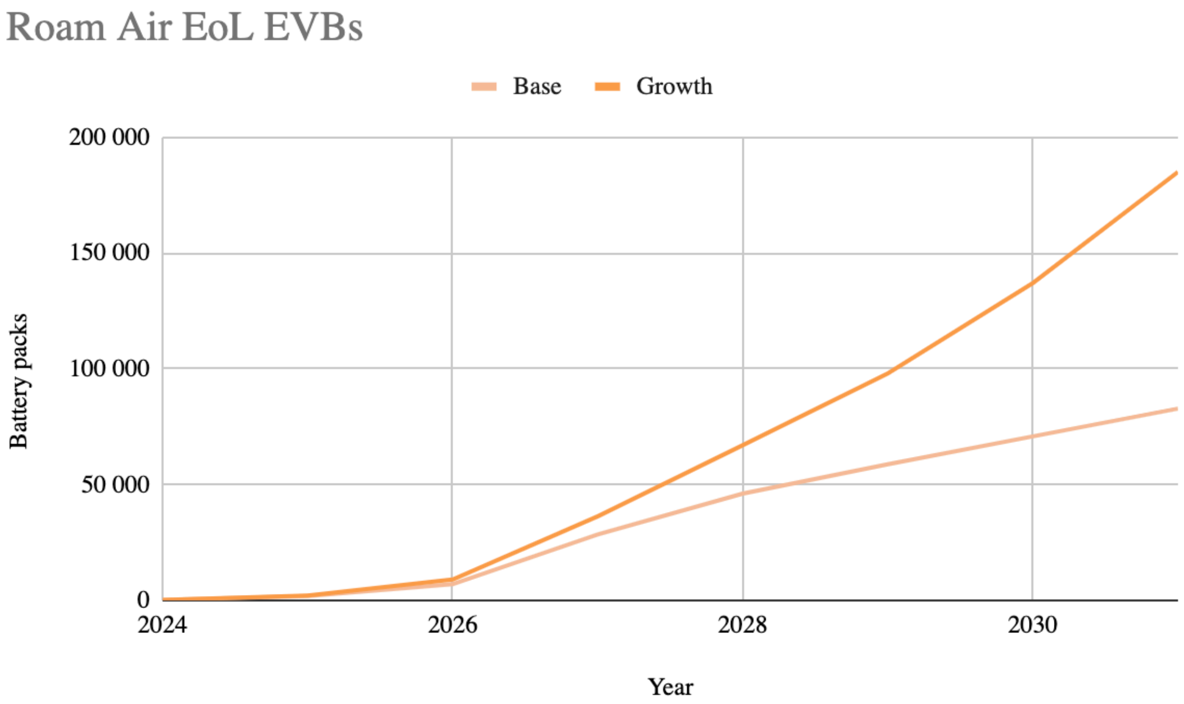

Figure 5.2. Predicted number of Roam Air EVBs reaching EoL.

To make the calculations more applicable for the market of second life applications, the size of the EoL market is translated from units to kWh in *Figure 5.3*. According to theoretical findings, an EVB should enter its second life at around 70-80% of its original capacity. An assumption of all Roam Air EVBs having 75% of their original capacity at EoL is therefore made.

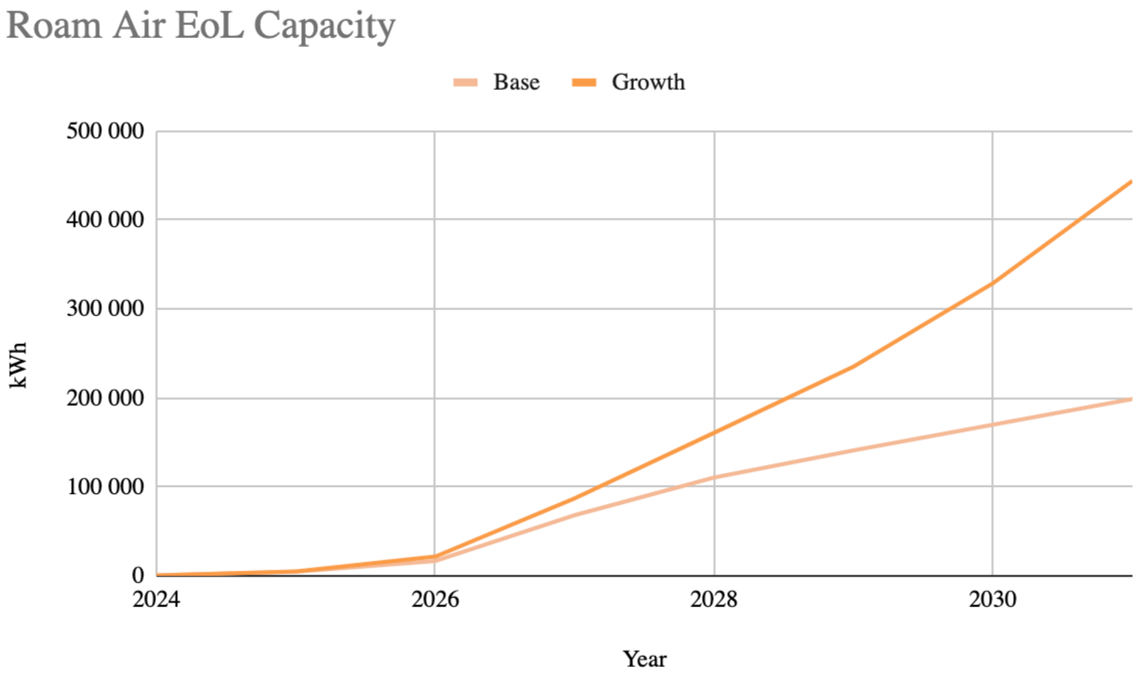

Figure 5.3. Predicted kilowatt hours worth of Roam Air EVBs reaching EoL using the assumption that all EoL batteries have an average of 75% of their original capacity.

5.2.2 Collection and EoL Usability

In combination with the market availability of EoL Roam Air EVBs, the collection rate and EoL usability are critical aspects in estimating the size of the second life market. As presented in *chapter 5.1.3*, the collection rate of EoL EVBs is dependent on infrastructure enabling effective collection as well as appropriate financial incentives. Furthermore, aligning with both the theory presented in *chapter 2.1.1* and empirical findings, not all EVBs reaching EoL can be repurposed, particularly those swollen due to accidents, causing safety risks which require direct recycling.

Accurately estimating the collection rate of EoL batteries is difficult, due to the Kenyan market being very immature and possessing different challenges compared to the currently more mature markets. As previously presented in the theoretical background, around 90% of all EVBs of BEVs were assumed to be collected within the EU as of 2018. Given that appropriate incentives, both in terms of financial compensation and ease of returning, are offered, it is assumed that a comparable share of Roam Air EoL EVBs can be collected.

In regards to using the Roam Air EoL EVBs for BESS, two different scenarios, illustrated in *Figure 5.4*, were presented in *chapter 2.1.1* and appeared during the empirical research:

- Building BESS using the EoL battery packs directly.
- Dismantling the EoL battery packs to cell-level and using them to build new packs for BESS.

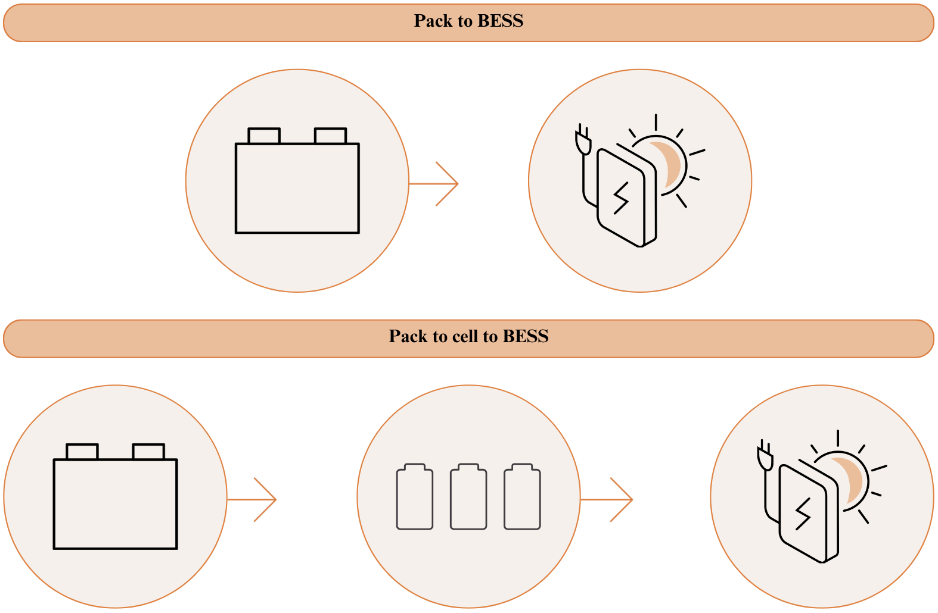

Figure 5.4. High-level illustration of the two alternative ways of building BESS using the Roam Air EoL EVBs.

These scenarios align with the theoretical background, but in the European market the second option is considered infeasible, due to the barrier of high labour cost identified in *chapter 4.3.1*. The empirical findings also align with the study conducted by Casals, Amante García, and Canal (2019) presented in *chapter 2.1.1,* stating that disassembling batteries to the cell level is not economically viable. Depending on the scenario, different assumptions regarding second life usability must be considered. When using the full packs, losses occur on pack-level. When dismantling to cell-level, on the other hand, losses occur at both pack- and cell-level, initially due to damaged cells and thereafter due to cell mismatches. A summary of the assumptions made, in collaboration with the case company, concerning the usability of the EoL EVBs is presented in *Table 5.2*.

Table 5.2. Assumptions made in regards to EoL EVB usability.

Pack-level
60% of all collected EoL packs are useable
Cell-level
80% of all collected EoL packs can be dismantled
80% of all cells are useable
10% of all useable cells are lost due to cell mismatches

Initially, 20% of all received packs are assumed to require direct recycling, due to being clearly damaged and thus posing a safety risk. According to findings made by Prevolnik and Ziemba (2019), presented in *chapter 2.1.1,* the share of EVBs entering return flows because of damage is expected to decrease from 50-60% to 2% the coming years, why 20% is considered reasonable. When building BESS on pack-level, it is further assumed that another 20% of the collected EoL EVBs need to go to recycling, due to individual cells reducing the capacity of the entire pack. As presented in *Table 5.2*, this means that 60% of all collected EoL EVBs are expected to be available for building BESS on pack-level. When instead building BESS after dismantling to cell-level, it is assumed that 80% of all cells, within the dismantlable packs, are usable. Both damages during the manual dismantling process and heavily run-down individual cells are taken into account. Finally, both European and Kenyan stakeholders, as well as theory, highlight the challenge of matching different cells and the importance of using cells with equal capacity when building battery packs using EoL EVBs. It is therefore assumed that 10% of all usable cells are lost due to cell mismatches when putting together the packs for the BESS. As all cells used for the Roam Air EVBs are identical, only losses caused by capacity mismatches need to be considered, which is why the share is kept relatively low. These estimations combined indicate that around 58% of the collected capacity is usable for building BESS on cell-level. *Figure 5.5* shows the estimated capacity, in kWh, of Roam Air EoL EVBs available for second life applications, again including both the base and growth scenario. For reference, the collected capacity, as presented in *Figure 5.3*, is also included in the graph.

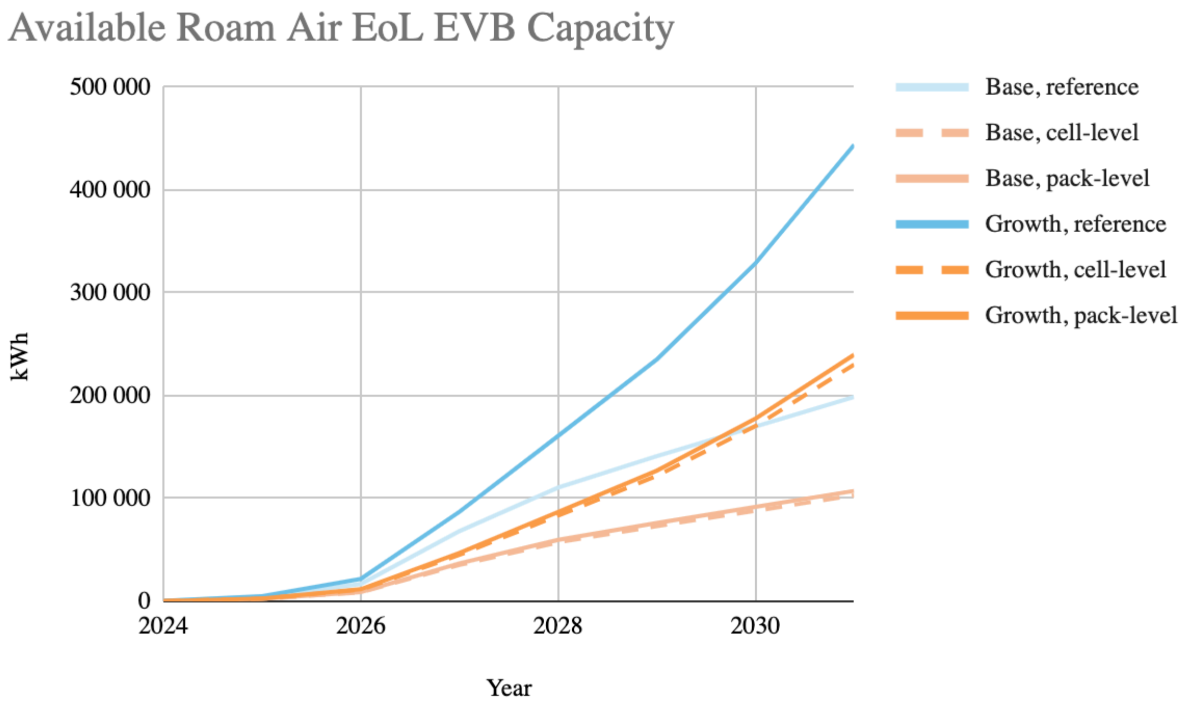

Figure 5.5. Estimated capacity of Roam Air EoL EVBs available for second life applications.

As can be concluded from *Figure 5.5*, the available capacity of EoL EVBs is almost the same if the BESS are built using the entire packs or individual cells of the Roam Air EoL EVBs. When rebuilding on cell-level, the calculated available capacity in 2031 ranges from 103 016 kWh, in the restrictive scenario, to 230 170 kWh, in the growth scenario. When rebuilding on pack-level, on the other hand, the calculated available capacity ranges from 107 309 kWh to 239 760 kWh using the base and growth scenario respectively. Based on available capacity, rebuilding on pack-level is preferred. Furthermore, this option is also less time consuming, technical, and costly, as it does not require full dismantling of batteries or rebuilding of new packs.

5.3 Building Business Cases

In this chapter, different business cases for the Roam Air EoL EVBs are built and presented. Initially, the second life applications are explored and thereafter, solutions for the final EoL EVBs are investigated.

As previously concluded, BESS is the preferred second life application according to both theoretical and empirical findings. In *chapter 4.2.2* the options of building BESS on either cell- or pack-level are introduced. Based on theoretical findings and current best practices from the European market, BESS are built on cell-level, but using high voltage hybrid inverters makes it possible to produce a BESS using entire battery packs. However, due to the uncertain capacity and lifespan of second life BESS, there is a potential risk of lacking interest or difficulties in adopting BESS built using repurposed EoL EVBs. This is both highlighted in the empirics, where stakeholders mentioned the challenges of raising funds for emerging second life applications, as well as in the theoretical background where warranty concerns and regulatory obstacles of adopting second life applications, due to the unexpected lifespan, are highlighted.

Therefore, three possibilities for second life applications are considered when building the business cases:

- BESS on pack-level
- BESS on cell-level
- No second life → Directly to recycling

Once the batteries have been fully utilised within BESS and upon reaching their final EoL with around 30% of their original capacity left, recycling is the next step in the modified CE model as presented in *Figure 2.11*. During the empirical studies, different perspectives on battery recycling within Kenya and the African continent emerge. Some stakeholders see the opportunity of opening an EVB recycling plant in Kenya within the near future, whereas others believe that it will never happen due to the lack of economic profitability. Additionally, aligning with the theory presented in *chapter 2.1.2* of batteries being categorised as dangerous goods, internal stakeholders mention the challenge of shipping the batteries abroad as that requires adherence to stricter regulations. On the other hand, markets abroad are more mature and recycling has reached profitability, as highlighted by Company G, why this could be a good business opportunity for Roam. This presents two distinct possibilities for recycling:

- Recycling in Kenya
- Recycling abroad

Combining the three scenarios for second life applications with the two scenarios for recycling, gives a total of six business cases, as presented in *Table 5.3*.

Table 5.3. The six developed business cases, with second life applications and recycling opportunities being presented on the horizontal and vertical axis respectively.

	Pack-level	***Cell-level***	***No second life***
Kenya	BESS are built using the EoL EVB packs. At the final EoL, the batteries are sent to recycling within Kenya.	BESS are built using the individual cells of the EoL EVBs. At the final EoL, the batteries are sent to recycling within Kenya.	All retrieved batteries are directly sent to recycling within Kenya.
Abroad	BESS are built using the EoL EVB packs. At the final EoL, the batteries are sent to recycling abroad.	BESS are built using the individual cells of the EoL EVBs. At the final EoL, the batteries are sent to recycling abroad.	All retrieved batteries are directly sent to recycling abroad.

However, due to lacking information in regards to Roam's recycling opportunities abroad, these business cases will not be included in the cost evaluation. Instead, recycling abroad will be used in the discussion as a potential solution but also as a best practice, indicating how the Kenyan recycling market can evolve. The business case in the upper right corner, further referred to as the baseline case, represents the as-is scenario, since Roam currently sells their unusable EVBs to Kenyan recyclers of WEEE, where they are kept in storage.

As identified in the empirical studies, BESS best serve their purpose within mini grids or standalone systems, which is why building BESS of five kWh is considered the most applicable EoL solution. In *chapter 2.1.1*, it is presented that the second life cycle of a battery is initiated when the capacity falls between 70-80%, why it is estimated that the EoL Roam Air EVBs have a capacity of 75%. As the original capacity of the battery packs is 3.2 kWh, building five kWh BESS using these batteries would therefore require just above two packs.

5.4 Summary

In this chapter, the first two research objectives are effectively addressed. The planned logistical flows of Roam's EoL EVBs are mapped out, complementing the already existing flows of their new EVBs to provide a clear understanding of how the batteries will be managed throughout their lifecycle. Additionally, the identified barriers and enablers, presented in *chapter 4.3*, are systematically addressed through a mapping of the prerequisites of Roam to effectively handle these challenges. The major strengths can be summarised as their existing infrastructure and strong sustainability core, whereas the most prominent areas of development consist of information flow to customers and data availability.

Furthermore, a second life application of five kWh BESS, used in mini grids or standalone systems, is identified to be the best suited for meeting the demands of the Kenyan energy market using EoL Roam Air EVBs. Based on clearly stated estimations and empirical findings, indicating that BESS can be produced either on pack- or cell-level, the expected market availability of EoL Roam Air EVBs in the coming years is calculated. The two options for producing BESS and a scenario with no second life application, combined with different recycling opportunities, are used to build business cases. The business cases, combined with the volume estimations, will be used to assess the viability of introducing a business unit for second life applications.

Building on these findings, the report proceeds in *chapter 6* to evaluate the various business cases, considering both financial and strategic aspects. As the data provided in the analysis and the estimates made are based on some uncertainty and assumptions, a sensitivity analysis will also be carried out. By combining the insights from the evaluation in *chapter 6* with those of this chapter, the last research objective and the research question can be addressed in the final concluding chapter.

6. Evaluation

This chapter proceeds to evaluate and compare the business cases presented in the previous chapter based on their financial performance. A sensitivity analysis is also conducted to explore the impact of uncertain and assumed values, and also to identify viable value ranges for strategic decisions. Other factors, such as sustainability and implementation feasibility, are also presented and evaluated from a strategic point of view. By following the evaluation, the case company should be able to design a second life application strategy best fitted to their operations.

6.1 Cost Evaluation

In assessing the viability of implementing a RL setup, a thorough financial assessment is essential, which is why this evaluation focuses on costs and potential revenues. Although various studies on predicting the price of second life applications exist, as presented in *chapter 2.1.1*, there is no established pricing model. Some studies base their models on factors like battery degradation and refurbishment costs but do not address the viability of a second life market at their calculated price points. In the cost evaluation presented in this study, battery degradation and refurbishment costs are used to determine a second life price. The process involves comparing the costs of the business cases against those of a baseline case, which reflects the current operations of the case company – paying e-waste recyclers to manage the EoL EVBs. Identifying precise costs and revenues is challenging due to the speculative new product and market, making estimations necessary. Nonetheless, the financial evaluation aims to provide insights into the potential financial benefits and risks of adopting a RL setup, and exploring the second life market for EoL EVBs. The cost evaluation is divided into two parts. The first introduces and explains the cost comparison model underlying its principles and logic, while the second compares the financial performance of the second life business cases to the baseline case.

6.1.1 Cost Comparison Model

To financially compare the potential business cases, costs are added to the process flow chart presented in *chapter 5.1.3*. Using the cost comparison model, the cost per BESS is calculated for the two second life business cases, which are then compared to each other and the baseline case. An overview of the cost comparison can be found in *Appendix B: Cost Comparison Calculations*.

The identified costs are divided into capital expenditures (CapEx), including necessary investment costs, and operational expenditures (OpEx), consisting of the costs of running the day-to-day business. The identified costs include the buyback, testing equipment investments, materials, labour, and packaging. With the exception of labour, all costs are expected to be the same for producing BESS on pack- and cell-level. However, as producing BESS on cell-level requires both disassembly and building new battery packs, this is assumed to be more time consuming, resulting in higher labour costs. According to case company estimations, building BESS on cell- and pack-level will require five and two hours of labour, respectively. Introducing a completely new Roam business unit will, for instance, also include extra warehousing, administrative, and distribution costs, which are not included in the cost evaluation. A summary of all included costs is presented in *Table 6.1*.

Table 6.1. Summary of all included costs.

Cost centre	***Estimated costs***
Buyback (good / scrap)	8% / 4% of EVB purchase price
Testing equipment	$40 000*
Material	$68
Labour (cell / pack)	$25 / $10
Packaging	$10

** CapEx.*

The initial investment cost of battery testing equipment, the only CapEx cost, is identified and estimated together with the case company. To calculate the annual CapEx costs, the total investments are divided equally between the eight years of 2024 to 2031, and potential interests are neglected. As volumes of EoL EVBs increase, new testing equipment will most likely be needed, however, this is not accounted for in these calculations. The OpEx costs are estimated together with the case company and compared to repurposing costs identified in theory presented in *chapter 2.1.1*, and then calculated to suit the cost comparison model. Apart from the buyback, all OpEx costs presented in *Table 6.1* are costs per BESS. To calculate the buyback cost, in USD per BESS, *Equation (6.1)* is used.

$$(6.1)\ Buyback\ per\ BESS\ =\ EoL\ EVBs\ *\ collection\ rate\ *\ \frac{buyback}{remaining\ capacity}\ *\ BESS\ capacity$$

In accordance with theory on trade-back models, presented in *chapter 2.2.3*, different buybacks are introduced depending on the remaining capacity of the battery. However, to make the solution more simple to implement, only two prices are introduced. One for batteries that are considered *"good"*, indicating that they are in good shape and have high enough capacity to be used in a BESS, and one for batteries considered *"scrap"*, meaning that they will go directly to recycling. Building on existing trade-back models, the battery owner receives a percentage discount on their next battery when returning their used battery, instead of receiving cash. Furthermore, in the cost evaluation, the buybacks are set at 8% and 4% of the purchase price of a new battery for *"good"* and "*scrap"* batteries respectively, where 4% covers the upfront cost of 37 USD. A discount of 8% also allows drivers to halve their daily instalments for over a month and is deemed effective in motivating action. After discussions with internal stakeholders who deemed a 20-30% discount as mentioned by Roam Air drivers too high, and even considered 10% excessive, an 8% discount is regarded as an appropriate starting point.

Aligned with the reasoning in *chapter 5.2.2*, 60% of batteries are considered *"good"* when producing BESS on pack-level, while 80% are considered *"good"* on cell-level. This part of the cost evaluation model limits the cell-level business case, as it includes giving out *"good"* discounts for returned batteries that will not be used for a second purpose. For the baseline case, where all batteries are sent directly to recycling, a discount of 4% is used for all returned batteries. As a margin of safety, the buyback is considered a cost in the cost evaluation model despite being proposed as a discount, even though there is a small possibility of them not being used by the battery owner. Furthermore, the revenues generated by the new batteries are not taken into account when calculating the costs and potential profitability of the business cases, though the buyback may generate increased sales.

The material costs are, together with the case company, divided into housing, connector, and other. It is assumed that the connector as well as other materials, including BMS, need to be imported, why shipping cost and taxes, both of 10%, are added. The housing, however, is assumed to be bought from a supplier within Kenya, removing taxes and making shipping neglectable. In *Table 6.2* the broken down material costs for building BESS are presented.

Table 6.2. Summary of the material costs per BESS before adding shipping costs and taxes.

Cost centre	***Estimated costs ($)***
Housing	20
Connector	20
Other, including BMS	20

As previously mentioned, some batteries and cells will go directly to recycling. A Kenyan e-waste recycler takes 150 KES per kilo of EoL EVBs, and as the Roam Air battery packs weigh 20 kilograms, this gives a cost of approximately 22.4 USD per pack. As presented in *chapter 5.2.2*, it is estimated that 58% of the collected EVBs can be used for building BESS on cell-level and 60% when building on pack-level. The remaining 42% and 40%, for cell- and pack-level respectively, are sent to recycling. In the baseline case, all collected EVBs are sent directly to recycling.

6.1.2 Cost Comparison

The cost comparison is used to compare financial aspects of the two potential business cases and the baseline case. *Figure 6.1* and *6.2* illustrate the annual costs for both business cases and the baseline case, given the base and growth volume estimations respectively. When solely comparing the costs, it is important to note that the baseline case does not have the capability of generating any revenues, given the current Kenyan market conditions. However, if the Kenyan market follows the more established European market, using a battery recycler will generate a revenue rather than a cost in the future.

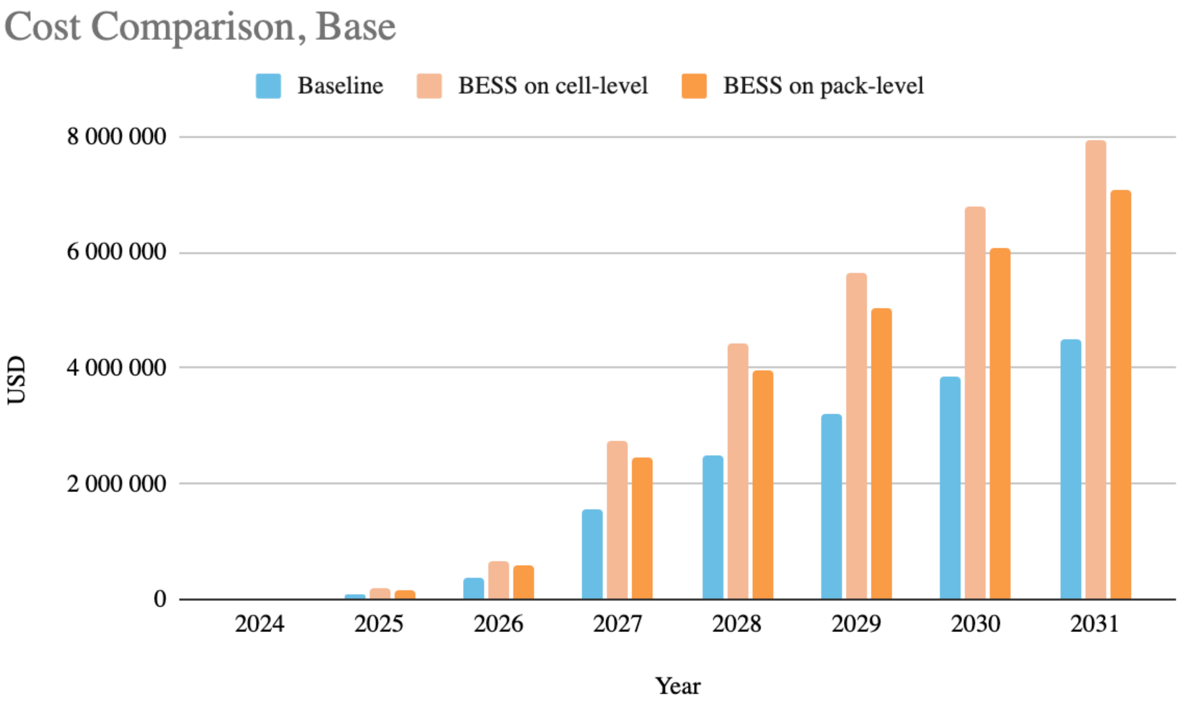

Figure 6.1. Cost comparison of the different business cases, given the base volume estimations initially presented in chapter 5.2.1.

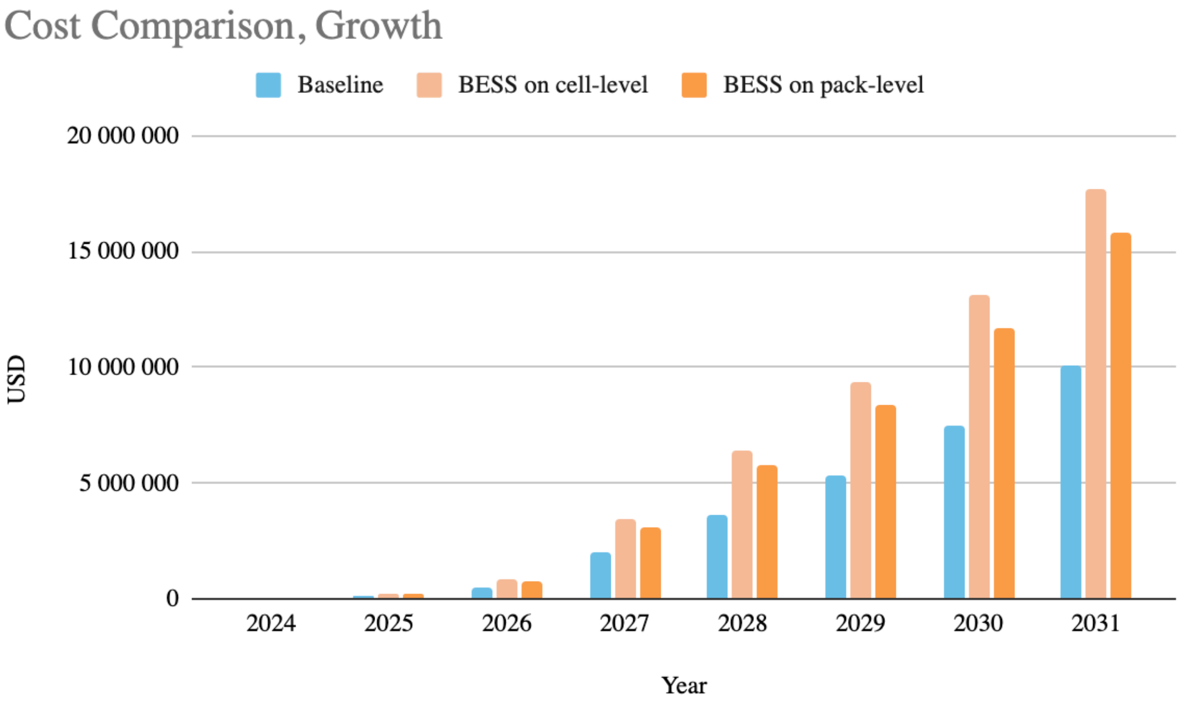

Figure 6.2. Cost comparison of the different business cases, given the growth volume estimations initially presented in chapter 5.2.1.

By analysing *Figure 6.1* and *6.2* it is evident that building BESS on pack-level generates lower costs than building on cell-level. The comparison between the graphs also indicates a slightly smaller cost differential between the business cases and the baseline case under the growth scenario, due to the investment costs being spread across a larger volume. Despite the additional costs associated with implementing a second life solution for EoL EVBs, it also opens up new revenue streams. Fulfilling EPR through scaling the baseline case, on the other hand, is not deemed economically feasible due to the current high costs of hiring e-waste recyclers in Kenya. Estimating the business worth of producing and selling BESS is made based on the available EoL EVB capacity presented in *Figure 5.5* in *chapter 5.2.2*. Discussions with internal stakeholders, experts within energy systems, a Kenyan BESS producer, and a consulting firm operating within renewable energy on the Kenyan market, as well as theoretical findings, indicate a business worth of 100 USD per sold kWh worth of BESS using second life EVBs. Given the business worth, the annual profits of the business cases are estimated and presented in *Figure 6.3* and *6.4*, given the base and growth scenarios respectively. As a point of reverence, the baseline case, and its increasingly negative profit, is also included in the graphs.

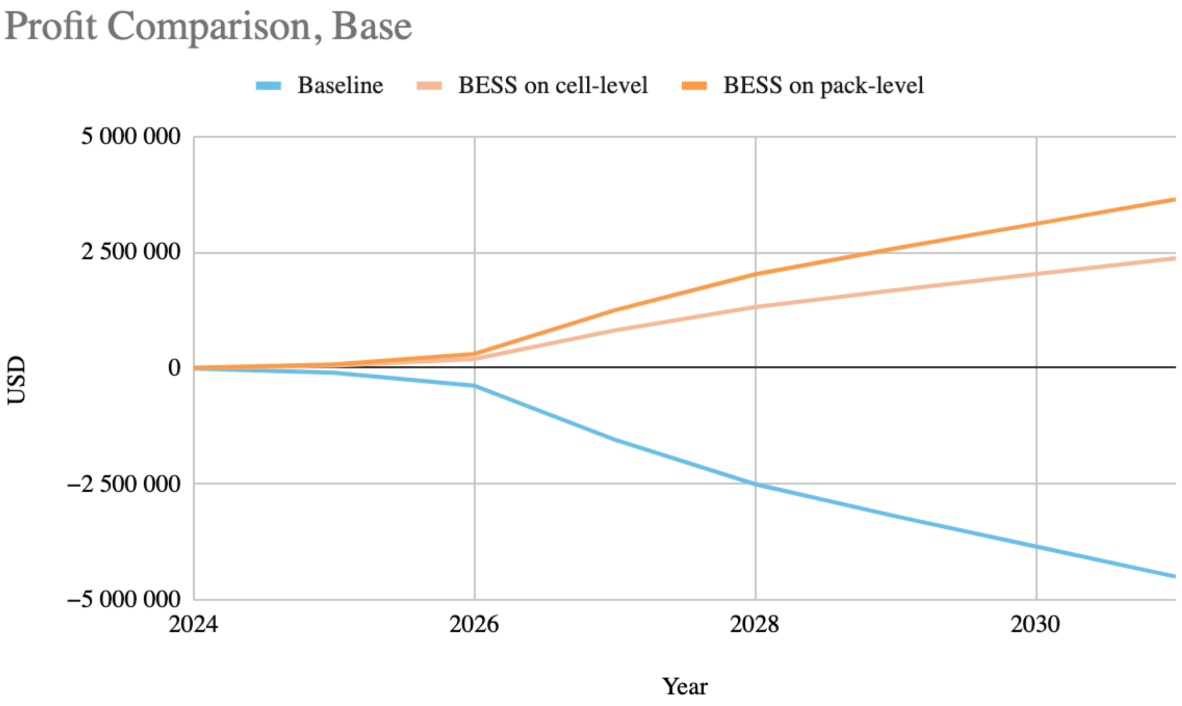

Figure 6.3. Profit comparison of the business cases and the baseline case, given the base volume estimations initially presented in chapter 5.2.1.

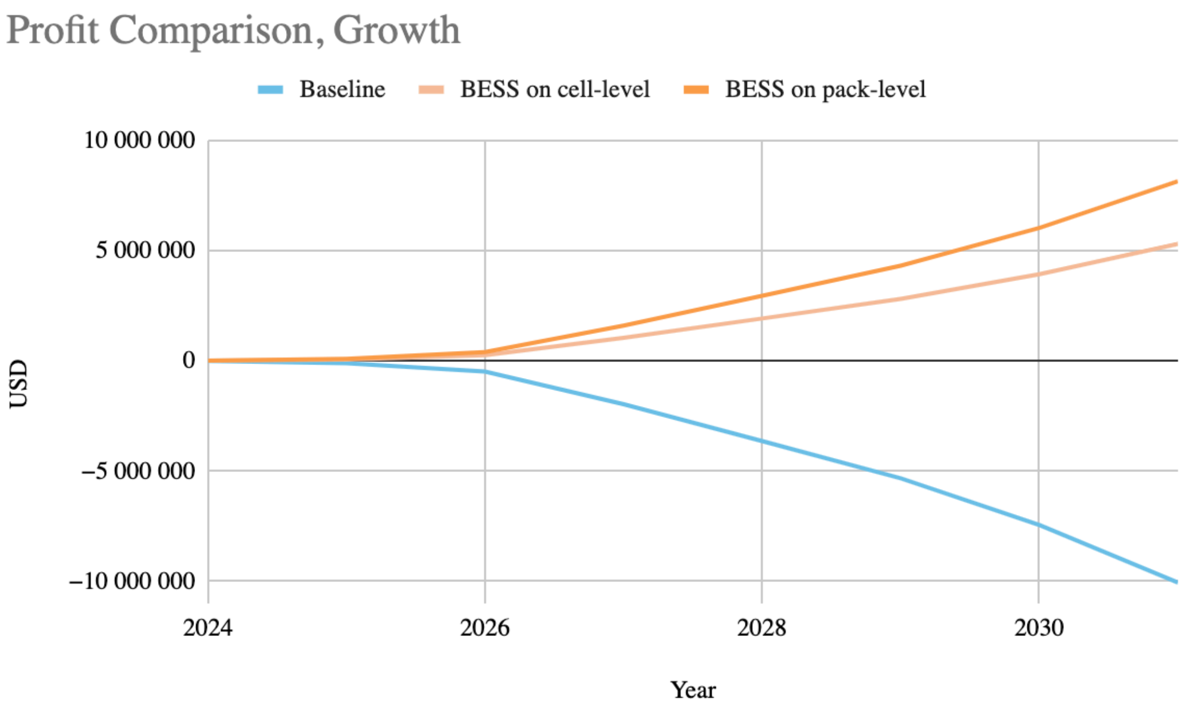

Figure 6.4. Profit comparison of the business cases and the baseline case, given the growth volume estimations initially presented in chapter 5.2.1.

The two business cases, given both the base and growth volume estimations, have positive profitability all years, with profitabilities growing substantially after the first three years. Given the highly costly solution of fulfilling EPR solely using recycling, going into the second life market should be preferred. Not only is it expected to be economically feasible, but it also contributes to increased environmental and social sustainability of the company. However, as the cost evaluation is dependent on many uncertainties, further analysis is necessary.

6.2 Sensitivity Analysis

The cost evaluation is based on various estimations, including future market predictions and speculative costs and revenues, which introduces uncertainty. To address this, a sensitivity analysis, assessing the model's robustness by examining its underlying assumptions, is conducted. Adjusting these parameters tests the resilience of the model and the viability of the different scenarios. If a parameter proves sensitive, the company needs to carefully consider how to manage that specific risk. Based on the estimations having the highest impact on the final results, the sensitivity analysis focuses on the following four key areas:

- Volume estimations
- Buyback
- State of collected batteries
- Market value

6.2.1 Volume Estimations

The estimations of the future EoL EVB volumes are based on both the company's expansion plan and the estimated lifespan of the batteries. Of these, it is the growth strategy that has the greatest impact on the results. While the company's growth strategy is ambitious, it remains speculative, making future projections uncertain. To account for this uncertainty, both a base and a growth scenario, based on the company's own estimations, have been analysed in the previous chapter. Even the restrictive estimates suggest a growth of 2 000% from 2024 to 2030 or an annual growth of approximately 65% during the same timeframe, indicating an optimistic trajectory.

The volume of motorcycles, and thus the volume of batteries, affects how many available EoL EVBs there will be. A larger battery inventory enhances the opportunities for successful second life initiatives. With a substantial supply of EoL EVBs, Roam has the opportunity to explore various repurposing strategies, from residential energy storage to grid support systems. Moreover, the number of mismatching cells will decrease as the volume of available EoL EVBs increases. As the largest share of costs are estimated to be associated with collecting the EoL EVBs and building the BESS, smaller volumes will not necessarily make the business cases unprofitable. On the other hand, investing a lot of time and money in a value proposition that only generates a small annual profit, might be considered the wrong priority.

Beyond financial considerations, there is an ethical and environmental argument for pursuing second life applications. However, the impact of these second life initiatives depends on the volume of available batteries. If the supply of EoL EVBs is limited, the environmental benefits that follow these repurposing efforts are also negligible. In essence, the "responsibility" argument for battery repurposing gains traction when there is a significant volume of batteries in circulation. Even without further sensitivity analysis on volumes, it is important for the company to consider this factor before moving forward with a second life application, especially given the difference in profitability in the base and growth scenario.

6.2.2 Buyback

The most substantial cost to consider is the buyback. As stated before, a buyback of 20-30% of the purchasing price is considered reasonable from discussions with end users, but deemed too high by internal stakeholders and compared to existing trade-in models. They argue that even a small discount can be enough, particularly for drivers satisfied with their electric motorcycles. These users often recognize the long-term cost savings of owning an electric bike compared to a gasoline-powered one, making them more prone to participate in a buyback program.

In the cost evaluation, a buyback of 4% of the battery purchase price is used for batteries considered *"scrap"* and 8% for batteries considered *"good"*. As the *"scrap"* buyback is determined by the upfront battery cost in the financing model, this is considered a minimum financial incentive for the Roam Air drivers, mainly consisting of daily earners, to return their EoL EVBs. To analyse the sensitivity of the cost comparison model towards the value of the buyback, only the *"good"* buyback is altered. When increasing the *"good"* buyback, producing BESS on cell-level, given both the base and growth volume estimations, obtains a negative profitability the first year using 9-11%, for two years using 12%, and all years using 13% and more. Producing BESS on pack-level is slightly less sensitive, as it retains a positive profitability until a *"good"* buyback of 11%, given both volume estimations. Thereafter, it obtains a negative profitability for one year when 12-16% are used, and a fully negative profitability using 17% and more. In *Table 6.3*, the *"good"* buyback discount giving the business cases a negative profitability annually are presented.

Table 6.3. The "good" buyback break even for each business case and year, given a "scrap" buyback of 4%.

	Cell-level, base	***Cell-level, growth***	***Pack-level, base***	***Pack-level, growth***
2024	9%	9%	12%	12%
2025	12%	12%	17%	17%
2026	13%	13%	17%	17%
2027	13%	13%	17%	17%
2028	13%	13%	17%	17%
2029	13%	13%	17%	17%
2030	13%	13%	17%	17%
2031	13%	13%	17%	17%

Discussions with internal stakeholders, however, indicate that implementing several buybacks will be too complicated at an early stage, and using a single buyback is therefore preferred. Through only using one buyback and tweaking the discount percentage, it is concluded that building BESS on cell- and pack-level, given both volume estimations, are expected to maintain an annual positive profitability for buybacks up to 7% and 8%, respectively. When increasing the buyback, producing BESS on cell-level obtains a positive profitability in the second year between 8-10%, and thereafter the profitability remains negative. When producing BESS on pack-level, on the other hand, a positive profitability is obtained in the second year using a discount of up to 11%, and thereafter it remains negative. The common buyback discount causing a negative profitability for each business case and year are presented in *Table 6.4*.

Table 6.4. The common buyback break even for each business case and year.

	Cell-level, base	***Cell-level, growth***	***Pack-level, base***	***Pack-level, growth***
2024	8%	8%	9%	9%
2025	11%	11%	12%	12%
2026	11%	11%	12%	12%
2027	11%	11%	12%	12%
2028	11%	11%	12%	12%

2029	11%	11%	12%	12%
2030	11%	11%	12%	12%
2031	11%	11%	12%	12%

Not surprisingly, given the results in *chapter 6.1.2*, producing BESS on pack-level is less sensitive to changes in the buyback cost. However, both business cases are sensitive to changes, and neither retains a positive profitability using the desired buyback cost of 20% mentioned by Roam Air drives. Given the large size of the Kenyan informal sector, in combination with the strong financial drive of the battery owners, the battery collection will most certainly be affected by the buyback. Therefore, there is a risk that the collection rate of the cost evaluation is overestimated, or that higher a buyback could lead to increased collection rates, making a higher buyback more feasible. Investigating how the collection rate and the buyback cost correlate would further improve the viability of the cost model. Thereafter, finding a sweet spot, with a buyback percentage high enough to encourage the majority of battery owners while still promising a good return, would be possible.

6.2.3 State of Collected Batteries

When building the financial model and tweaking the numbers used, it is concluded that the model, and hence the financial feasibility, is highly sensitive to changes regarding the state of the collected batteries. For the calculations made on building BESS on pack-level, this includes the share of collected battery packs that are usable for second life purposes, excluding the ones with low remaining capacity or visible damages. For the calculations made on building BESS on cell-level, it also includes the share of individual cells that are unusable within the usable packs as well as the share of cells lost due to cell mismatches. All numbers used in the cost comparison, presented in *chapter 6.1.2*, are presented in *Table 5.2* in *chapter 5.2.2*.

In addition to these numbers having a high impact on the results, they are also speculative given the challenge of limited data availability. Furthermore, most available data is European and based on car batteries, which does not accurately reflect the conditions of the studied EVBs in Kenya, especially considering the distinct driving habits and usage patterns of heavy loaded motorcycles in continuous operation. Without a comprehensive analysis on this, the model relies on estimates conducted together with the case company. Given the high impact of these parameters on the financial outcomes, it is important to understand how changes in the condition of the collected batteries affect profitability. For instance, the sensitivity analysis shows that if only 33% of batteries are reusable for BESS on pack-level, instead of the assumed 60%, profitability is compromised for all years. At cell-level, three different percentages can be altered, however, it is assumed that the percentage of available cells after cell mismatches will increase as the volume of EoL EVBs increase. Consequently, adjustments will only be made to the percentages of reusable cells and batteries. In scenarios where the percentage of reusable *cells* decreases to 59%, from the assumed 80%, the business case will not be profitable. This is if the amount of reusable batteries, those unaffected by external factors like swelling, stay constant at the expected 80%. The same results are retrieved when the percentage of reusable *packs* are decreased, keeping the share of reusable *cells* at a constant. This means that if a total of 47% of collected cells are usable for building BESS, before losses due to cell mismatch, the business case will not yield any profit. *Table 6.5* shows the percentages of batteries and cells that are reusable for BESS for both cell- and pack-level, highlighting the conditions under which the business cases yield annual negative profitability.

Table 6.5. The share of collected cells and packs reusable for BESS causing negative profitability, given each business case and year.

	Cell-level, base	**Cell-level, growth**	**Pack-level, base**	**Pack-level, growth**
2024	62%	62%	48%	48%
2025	48%	48%	34%	34%
2026	47%	47%	33%	33%
2027	47%	47%	33%	33%
2028	47%	47%	33%	33%
2029	47%	47%	33%	33%
2030	47%	47%	33%	33%
2031	47%	47%	33%	33%

6.2.4 Market Value

As highlighted in *chapter 4.3.2,* second life BESS are up against the large-scale production of new batteries from China. Currently valued at 100 USD per kWh, second life systems are strategically priced below BESS using new batteries. However, with the ongoing development of the Chinese market and the continuous decrease in price of new batteries, it is crucial to determine the break even point of Roam's second life BESS production. This point indicates that when producing second life BESS is no longer profitable and it also represents the threshold at which Chinese battery prices can decrease before second life systems lose their competitive edge. In the cost evaluation, a business worth of 100 USD per kWh is used for the entire time period studied, and with the purpose of analysing the sensitivity of the model this value is altered. *Table 6.6* presents the business worth, in USD per kWh, giving the business case a negative profitability annually.

Table 6.6. The business worth break even value for each business case and year.

	Cell-level, base	**Cell-level, growth**	**Pack-level, base**	**Pack-level, growth**
2024	$96	$96	$84	$84
2025	$78	$78	$67	$67
2026	$77	$76	$66	$66

2027	$76	$76	$65	$65
2028	$76	$76	$65	$65
2029	$76	$76	$65	$65
2030	$76	$76	$65	$65
2031	$76	$76	$65	$65

With the low expected available EoL EVBs of 2024, the table shows that both business cases, though especially producing BESS on cell-level, are sensitive to changes in business worth. Producing BESS on cell-level obtains a negative profitability at a business worth of 96 USD already, whereas producing BESS on pack-level obtains a negative profitability at a business worth of 84 USD. However, as the business worth of new batteries is expected to decrease with developed technology and increased mass production, it is more interesting to analyse the retrieved results in a couple of years. This is further strengthened by the fact that implementing a business unit for second life applications of EoL EVBs will take time, both for Roam and other EV manufacturers. From 2027 and onwards, the tipping point is represented by a business worth of 76 and 65 USD for cell- and pack-level respectively. With prices of new batteries currently heading towards 100 USD, it is only a matter of time before prices are pushed further, squeezing the profitability of the entire second life market. Before entering the second life market, it is therefore important to make sure that the business case is financially viable even with a decreased market worth.

6.3 Qualitative Analysis

This chapter explores the qualitative factors influencing the implementation of a RL setup and second life applications for EoL EVBs. Key areas of focus include sustainability, implementation feasibility, and recycling opportunities. By examining these aspects, the aim is to provide a comprehensive evaluation of the challenges and benefits associated with RL and second life applications, beyond the financial ones. This analysis will help determine the overall viability and strategic alignment of these initiatives with the goals of the case company.

6.3.1 Sustainability

Sustainability is a key factor in implementing a RL setup and repurposing EoL EVBs. While end users might not prioritise sustainability, it is crucial for aligning with Roam's strategic goals. The emphasis on *environmental* sustainability is reflected in Roam's corporate strategy and their mission of electrifying the Kenyan vehicle fleet. The commitment to sustainability and CE principles is not only important to Roam's identity, but also enhances its reputation and attractiveness to environmentally conscious investors. Therefore, sustainability plays an important role in Roam's overall business strategy.

Firstly, extending a battery's overall lifespan through repurposing offers significant environmental benefits, as presented in *chapter 2.1.1*. By reducing the need of producing new batteries, the environmental and social impacts associated with battery production are decreased.

Moreover, the environmental impact obtained during the initial production is spread over a longer period, resulting in a reduced environmental impact from a lifecycle perspective. Quantifying environmental benefits can be a compelling marketing strategy, especially when approaching investors. As a startup, Roam relies heavily on investors, making it important to demonstrate environmental responsibility alongside financial viability. Therefore, by highlighting the environmental advantages of prolonging the battery lifespan, Roam can demonstrate a tangible return on sustainability, enhancing the appeal to potential investors.

Secondly, compliance with various environmental laws is also a crucial aspect. By implementing a RL setup, Roam not only fulfils the EPR law in Kenya, and other local regulations, but also aligns with European laws and initiatives. As EU regulations frequently set global standards, supported by theory presented in *chapter 2.1.2*, Roam would be at the forefront if similar laws were adopted across Africa, positioning the company as a leader in environmental compliance and sustainability.

Lastly, by retrieving these batteries, Roam ensures social sustainability. Through safe and responsible handling, the environmental risks associated with improper disposal are minimised, and individuals operating within the informal sector are protected from potential harm. Moreover, repurposing these batteries as BESS can address critical energy needs in underserved areas, lacking reliable electricity access. This initiative provides essential energy solutions where they are most needed, which could position Roam for external grant opportunities from organisations like the UN or Sida. Considering the energy access challenges in Kenya's neighbouring countries, as presented in *chapter 2.3.2*, producing BESS using EoL EVBs also provides opportunities for scalability.

6.3.2 Implementation Feasibility

The feasibility of implementing an RL setup and a second life market for EoL EVBs involves several considerations. Roam must assess technological readiness, safety aspects, stakeholder engagement, regulatory compliance, and operational challenges to determine the viability of the initiative. Safety aspects are particularly crucial, as the repurposing of EoL EVBs must ensure that the batteries do not pose risks such as overheating, leakage, or catastrophic failure during either production or their second life. Though building BESS on pack-level seems the most promising from a financial point of view, this might not be the case when considering safety aspects, why rigorous testing and certification processes to meet stringent safety standards are of high necessity. While the concept of repurposing EoL EVBs and implementing a RL setup is promising, its successful implementation also depends on practical aspects like resource availability, infrastructure requirements, and stakeholder cooperation. Therefore, the qualitative analysis seeks to answer the fundamental question – Is it achievable?

In *chapter 2.2.3*, an eight step framework for successful implementation is introduced, providing a structured approach to manage transformation initiatives. The framework includes steps such as defining the need, planning, executing, and monitoring progress, which are essential for guiding the project towards its goals. By integrating the prerequisites identified in *chapter 5.1.4* with this eight-step framework, the significance and contribution of each element to the implementation's feasibility can be evaluated. The company must first evaluate its current infrastructure to determine the viability of using, for instance, existing hubs and integrating testing equipment on-site, alongside assessing the technological capabilities required to develop new second life applications for their EoL EVBs, whether it is on cell- or pack-level. Additionally, the readiness of the energy department and software team to support these new processes is crucial. The need for RL and EoL handling must be clearly defined based on market demands and environmental impacts, and by looking at Roam's growth strategy there is an increasing need to address the batteries reaching EoL. To manage this transformation effectively, Roam will require a dedicated transformation team that includes key departments, such as the energy division for product development of a BESS and the software team for robust data management. It is also essential to establish clear success criteria that align with the sustainability goals and market expansion plans. Although the estimated profit has been outlined in the cost evaluation, it is important for the company to set its own specific goals. As noted in *chapter 5.1.4*, there is a significant need for clear communication with all stakeholders, particularly end users, necessitating the development of a comprehensive communication plan. This plan should ensure that all stakeholders, including customers and internal teams, are informed about the EoL handling processes and the benefits of RL.

In executing the change plan, it is critical to focus on integrating EoL EVBs into Roam's existing operations. Lack of knowledge and preparation are common factors leading to implementation failures and therefore, leveraging the company's market presence and product knowledge is crucial to facilitate the adoption of the new processes. By doing so, Roam can effectively manage the transition towards a sustainable and efficient RL setup and second life market for EoL EVBs, ensuring both environmental responsibility and business viability.

6.3.3 Recycling Opportunities

As discussed in *chapter 5.3,* the options for recycling EVBs in Kenya include domestic recycling or sending the EoL EVBs abroad to Europe or back to the battery producer in China, for instance. Currently, there are no EVB recycling plants on the African continent, but empirical findings suggest that e-waste handlers are exploring the viability of establishing recycling facilities capable of producing black mass. However, for recycling to be profitable there needs to be a significant increase in EVB volumes, and even though both presented theory and forecasts from Roam suggest a great increase, this will take a couple of years and even more before they reach the stage of recycling. Moreover, established recycling markets tend to be where battery producers are located, allowing for efficient recycling of scrap material before EVB volumes reach significant levels. Since there are no major EVB producers in Kenya, initiating recycling facilities in the country would only be viable if battery production or EVB volumes increase substantially.

If the Kenyan battery market matures similarly to Europe's and the value of black mass exceeds recycling costs, there could be a financial opportunity for Roam to sell their EVBs to recyclers. However, there are more aspects, like advancements in battery production aimed at reducing costs and therefore trying to find cheaper cathode materials, potentially limiting the profitability of recycling altogether, to consider. This uncertainty highlights the complexity of the future recycling market in Kenya, with indications suggesting it may never become profitable. However, without any recycling in the country, there is a significant risk of everything ultimately being disposed of in landfills, especially with the forecasted increase in EVB volume.

The scenario where no recycling plants are opened in Kenya may lead to the need of sending EoL EVBs abroad for recycling, even though this is not currently considered a viable option by internal stakeholders. In Europe, many recyclers pay for old EVBs since they can make a profit from the recovered materials. Due to the similarly mature Chinese market, this is expected to be the case there as well. Ideally, sending batteries back to the producer in China for recycling would be preferable, as the retrieved materials could be reused in production, allowing Roam to claim the use of recycled material in their batteries. However, the viability of this option remains uncertain, with potential barriers such as shipping costs and regulatory constraints governing waste transportation. When shipping full containers, the shipping cost per bought battery, as presented in *chapter 4.1.3*, is approximately 5 USD. The current recycling option within Kenya costs around 22.4 USD per battery, as presented in *chapter 6.1.1*, leaving room for costs specifically associated with EoL transportation. Given the expected increase in EoL EVBs and the more mature recycling markets abroad, shipping full containers back to China would most certainly make the financial results of the baseline case better and could even result in a positive profitability.

6.4 Summary

Concluding *chapter 6*, this section summarises the key findings from the conducted evaluation. The chapter included a comprehensive cost comparison among the business cases, a sensitivity analysis of critical parameters, and a qualitative assessment of areas that could not be quantitatively investigated.

Through this chapter, the last research objective has been effectively addressed as both profitability and sustainability of the business cases have been examined. It is evident from the evaluation that both presented options are profitable, with the pack-level option emerging as the most profitable. Based on these insights, it can be concluded that as long as the market is ready for a second life application, investing in such a strategy appears to be advantageous for the case company. Additionally, when assessing the robustness of the model and alternative scenarios, it becomes clear that obtaining accurate real-world data is vital before implementing RL as many parameters are speculative and can significantly impact the outcome.

Furthermore, it is essential to recognise the significance of market readiness and the potential impact of external factors on the success of RL initiatives. Therefore, thorough market research and strategic planning are imperative for the effective implementation of RL and second life strategies. Moreover, as highlighted in the theoretical framework, aligning the SC strategy with the overarching corporate strategy is important for organisational success as this alignment ensures that the SC functions are part of the broader objectives and goals of the company. In line with this principle, the two business cases proposed for the case company not only demonstrate profitability and sustainability but also seamlessly integrate into the company's portfolio and can contribute to Roam's overall strategic vision. Roam's ethos of electrifying all of Africa aligns perfectly with the BESS business case as Roam can be part of extending electricity access to rural areas, empowering communities and fostering economic development.

7. Conclusion

The concluding chapter of the thesis summarises the key findings, addresses the research objectives, and answers the research question. Alongside fulfilling the purpose of the thesis, it also discusses the theoretical and practical contributions. Additionally, it suggests potential areas in need of future research and exploration. Finally, it reflects on the writing process and lessons learned during the thesis journey.

7.1 Answering the Research Objectives and Research Question

The purpose of the thesis – *to, from a reverse logistics point of view, develop and evaluate actionable strategies enabling an efficient and sustainable end-of-life handling of electric vehicle batteries in Kenya* – is addressed through answering the research objectives and research question.

Beginning with **RO1**, – *map the current and planned logistical flows of the Roam Electric motorcycle batteries* – a flow chart of the current logistical flows is provided in *chapter 4*, while *chapter 5* further discusses potential future flows. The key finding is that existing infrastructure designed for outgoing flows can be leveraged for return flows, with hubs serving as collection points for the EoL EVBs. However, as production volumes increase, thus also the volume of EoL EVBs, more hubs, storage, and larger facilities will be needed. Importantly, these expansions will occur alongside increased motorcycle production, as they are required not only for the implementation of RL.

Enabling infrastructure is important in overcoming barriers of RL, and thus addresses **RO2**, – *map the barriers and enablers of implementing a reverse logistic setup of end-of-life electric vehicle batteries* – with barriers and enablers outlined in *chapter 4* and further discussed in *chapter 5*. By also mapping barriers and enablers applicable to the more mature European market, potential barriers for the Kenyan market can be identified and addressed. The majority of identified barriers are within the categories *financial and economical*, *law and regulation*, and *infrastructure and technology*, including major barriers like challenges in raising funds, insufficient governmental policies, and technological limitations. On the contrary, economic incentives, increased data availability, and information flows regarding EoL handling are enablers for RL implementation and also manageable for a company to address.

As for **RO3**, – *suggest viable, and economically sustainable, reverse logistic setups for the environment in which Roam Electric operates* – both presented business cases fulfil the research objective. According to the cost model in *chapter 6* they generate profit, and both are environmentally and socially sustainable through prolonging the lifespan of the batteries, highlighted in the sustainability discussion in the same chapter. However, while the parameters used in the profit comparison are compared with theory, they are highly dependent on assumptions made in coherence with the case company, creating uncertainty. For instance, if motorcycle sales are significantly lower than expected, or if the market value drops, profitability will be affected, potentially making the business cases unviable. The sensitivity analysis gives an insight into the sensitivity of the estimated parameters included in the model and also serves as a basis for informed decision-making, allowing the case company to navigate the emerging market conditions effectively.

***RQ**: How can a Kenyan electric vehicle producing company benefit from implementing a reverse logistics setup and end-of-life handling strategy for electric vehicle batteries?*

Lastly, addressing the research question, the thesis concludes that a Kenyan EV producing company can benefit from implementing a RL setup and EoL strategy for EVBs by creating new business models around second life applications, such as BESS. This requires the appropriate conditions, including sufficient volumes of usable EoL EVBs, aligned incentives across the SC, available technical capabilities, and coherence with the overall corporate strategy. Succeeding with implementing RL does not only align with global sustainability goals through mitigating environmental impact, but also enhances economic value by leveraging CE principles to extend the life cycle of batteries through repurposing and recycling. Furthermore, it strengthens the company's market position and long term viability through attracting environmentally conscious investors and contributing to economic and social development.

7.2 Contributions

From a theoretical point of view, the thesis contributes to SC theory by integrating RL with EVB theory through a detailed single case study, and applying it to the Kenyan context. It applies established theories to a new context, assessing the Kenyan market's current maturity and its connection to an emerging second life application market. Additionally, it contributes to theory by exploring how CE principles can be implemented in less developed markets to enhance sustainability and economic viability. Overall, the thesis advances the understanding and integration of CE theory, RL, and the evolving second life market landscape of a developing country.

For the practical contribution, the thesis provides EV producers in Kenya with a thorough understanding of the barriers and enablers for implementing a RL setup. After concluding on the most suitable second life applications for the Kenyan market, two distinct business cases are presented, discussed, and assessed based on their financial performance and alignment with various business and SC strategies. The financial sensitivity of the business cases is also assessed based on several parameters, using a cost evaluation model shared with the case company. Specifically, the thesis offers the case company an overview of the challenges and advantages associated with implementing a RL setup for *their* EVBs, intended for use in second life applications.

7.3 Limitations and Future Research

The thesis focuses on how a company can implement a RL setup and use their EoL EVBs for a second life application. However, due to time constraints and data limitations, certain aspects remain open for further investigation. First of all, the thesis is based on a single case company, analysing its specific capabilities and limitations. To enhance the study's depth, conducting multiple case studies could provide more nuanced insights, particularly regarding prerequisites for addressing identified barriers. With additional time, it would also have been interesting to conduct a quantitative mapping of the EoL market, rather than relying solely on the qualitative approach of the study.

A second interesting extension of the study would be to structure and evaluate the implementation of the RL setup. The thesis is exploratory, expanding on what needs to be addressed to implement a RL setup and develop a second life application, but it does not cover the implementation plan or a plan for performance evaluation when a strategy is implemented. Additionally, considering all the assumptions made in the calculation, it would be beneficial for the case company to use the sensitivity analysis and further develop the calculations. Particularly, it would be beneficial to identify the point at which *demand meets supply* for buyback and collection rates, as a higher buyback rate is likely to result in increased collection rates.

Another aspect worth considering is the exploration of various recycling opportunities. While the thesis primarily focuses on secondary application possibilities, a potential emerging recycling market in Africa presents an interesting area for further study. These extensions have the potential to deepen the understanding of the subject further. Furthermore, the model used in the thesis can be enhanced by incorporating more complex assumptions and calculations. For instance, treating buyback as a cost oversimplifies its impact, as it essentially acts as a discount on a new battery, thereby affecting the profit per battery. Additionally, extending the model to include more years could provide valuable insights into the future by allowing for a more comprehensive analysis of long-term trends and patterns.

Finally, we hope and believe that this thesis will help the case company, and other companies of similar nature, with their work on second life applications of EoL EVBs, making it contribute to sustainable development through integrating CE principles, innovation, and logistics.

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9. Appendix

9.1 Appendix A: Interview Questions

9.1.1 General Questions

1. Could you start by presenting yourself and your role at the organisation?
2. Could you give a short presentation of your organisation?
3. In what way is your organisation connected to EVBs?
4. How can the public sector contribute to the EVB market becoming more circular?
5. How can the private sector contribute to the EVB market becoming more circular?
6. From your experience, what do you believe are the main barriers within the listed categories for implementing reverse logistics of EoL EVBs?
    a. Financial & Economical Related Barriers
    b. Knowledge & Experience Related Barriers
    c. Law & Regulation Related Barriers
    d. Management & Organisational Related Barriers
    e. Infrastructure & Technology Related Barriers
    f. Environmental Related Barriers
    g. Market & Social Related Barriers
    h. Policy Related Barriers

9.1.2 Specific Questions – Understanding the Case Company

1. What is your business model?
    a. What do suppliers provide and what do you do in-house?
    b. What are your revenue streams?
    c. Do you see any potential in changing your business model?
2. How many motorcycles are currently on the market and how many are expected to enter the market in the coming years?
    a. How many battery packs are there per motorcycle?
3. What is the expected number of batteries reaching EoL in the coming years?

Battery

1. What type of batteries does Roam use?
2. Do you design the batteries yourself?
    a. What attributes of the design affect the performance?
    b. What aspects do you consider when choosing suppliers?
3. What is the expected life-time of Roam's EVBs?
    a. At what capacity can it no longer be used in motorcycles?
    b. Which parameters affect the SoH of the batteries?
4. What enablers and barriers do you see in regards to EoL handling?
    a. What do we need to know in order to qualify what the battery can be used for their second life?
    b. What is needed to repurpose the batteries or to take them apart for recycling?
5. What information do you get out of your BMS?
    a. Are there any plans of extending this?

    b. Can the Roam bike be used with other batteries and vice versa?

Operations

1. What specific goals does Roam have regarding absolute growth and market-share growth?
2. When do you plan that Roam will be profitable?
3. Do you have a supply chain strategy?
    a. How is it aligned with the overall corporate strategy?
4. Can you explain the current flows of the batteries?
5. EVB supplier
    a. Do you use one or several EVB suppliers?
    b. What aspects do you keep in mind when choosing suppliers?
        i. How are these prioritised?
    c. Do you know anything about their possibilities of repurposing or recycling batteries?
    d. Do you see any potential of the supplier buying back your EoL EVBs?
6. How would you describe the typical end-customer?
    a. Do you think they would return batteries to you (or Company D) if they had the right incentives?
    b. What incentives do you think they would need?
7. Can you tell us a bit more about the Roam hubs?
8. Looking at the CE butterfly diagram, what return flows do you believe would make most sense to implement at Roam?

Sustainability

1. Do you have a sustainability strategy?
    a. If not, how is it supposed to change in the coming years?
2. How is it aligned with the corporate strategy and supply chain strategy?
3. Could you go through relevant Kenyan regulations affecting your business? EPR?

9.1.3 Specific Questions – Understanding the Potential Return Flows and EoL Handling

Company A, Company H and Company I

1. Do you know what share of batteries (and specifically EVBs) currently end up in landfills?
2. Are there any standards on EoL processes for EVBs?
    a. Do you need to follow any regulations for collecting and transporting the batteries?
3. What do you do with the collected batteries?
    a. What information do you need from the EVB in order to determine its state of health and thus what it can be repurposed as?
        i. How would your business benefit from handling batteries with battery passports?

    b. Do you handle damaged batteries (e.g. swollen or leaking ones) differently than "regular" EoL batteries?
7. What is normally the state of the batteries you receive? Have they reached EoL due to cycle ageing or accidents?
8. How do you maintain safety when handling hazardous goods?
    a. What do the prerequisites for recycling look like?
9. In terms of recycling, what would make the most sense – turning it into black mass or dismantling it into as many discrete streams as possible?
10. From our understanding, many other operators use LFP batteries – are there any major differences affecting your business model / way of working when handling LFPs vs. nickel based batteries?
    a. Standardisation
    b. Possibility of second life
    c. Potential revenues from recycling
    d. Costs
    e. Expected margins
11. Have you come in contact with battery packs from motorcycles?
    a. Do you see any problem with using smaller batteries for energy storage?
    b. Are they easier or more difficult to reassemble?
12. Are there any economic incentives for recyclers, e.g., tax breaks, subsidies, economic support, and the introduction of deposit refunds?
13. Do you see any trends making battery repurposing or recycling more popular?
    a. Is there a market for recovered batteries?
    b. What applications do you see for second life batteries?
14. Are you planning on expanding your current business model / value proposition to include more services?
    a. Do you expect it to generate a better profitability?
    b. Do you see a future where Roam, and other operators within the industry, could sell batteries to you?

Company B and Company C

1. What is your take on the Kenyan energy market – what are the biggest obstacles?
2. What is the need for a second life EVB in society?
    a. Eg. Reuse, energy storage, equalising intermittent energy sources, back-up
3. Are there any policies or regulations that could contribute to the business becoming more sustainable?
    a. Are there any specific regulations or policies that come to mind?
4. Are there any economic incentives for repurposing / recycling, e.g., tax breaks, subsidies, economic support, and the introduction of deposit refunds?

Company D

1. How long does it typically take for your customers to take ownership of the batteries?
    a. Is this the standard model for all customers, or is it only for the Roam Air?
2. How would an ideal return flow of EVBs look to you?
3. What do you believe would hinder your end customers from returning the batteries?
4. What incentives would your customers require to return the batteries?

5. Let’s say that Roam implements a reverse flow of their EVBs – In what way do you believe that you would be involved in the chain?
    a. Do you see any risks or opportunities with the involvement?
    b. Do you have a plan for EoL batteries in house?

Company E and Company F

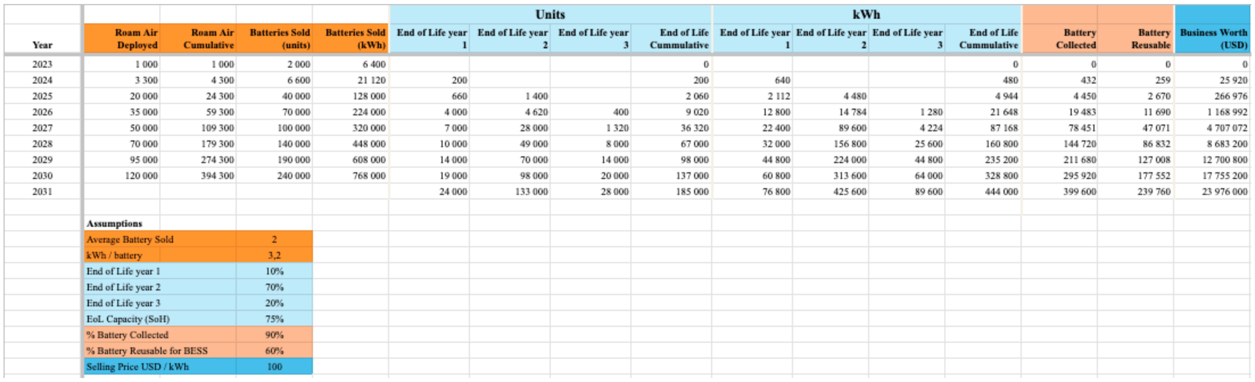
1. From your experience, how much of the EVBs initial capacity is normally left when they are repurposed?
2. As of today, what share of EVBs enter their second life cycle?
    a. What information do you need from the EVB in order to determine its state of health and thus what it can be repurposed as?
3. From your experience, what have been the biggest obstacles of making the business work?
4. How do you keep on track with all regulations? What are the major challenges?
5. Have you come in contact with battery packs from motorcycles?
    a. Do you see any problem with using smaller batteries for energy storage?
    b. Are they normally easier or more difficult to reassemble?
1. How do BESS become profitable?

Company G

1. What do current return flows look like (in broad terms)?
2. How would you say that your flows will change in the coming years?
    a. Volumes?
    b. Will there be a shift from faulty batteries to end of life?
    c. Do you see the batteries entering a second life cycle before going to recycling?
3. From your experience, what have been the biggest obstacles of making the business work?
    a. We are thinking in terms of collecting EVBs, regulatory aspects etc.
4. What do you see as the main enablers of EoL EVB handling?
5. If solely looking at the outputs of the battery recycling (and excluding for instance labour costs), would another way of battery recycling be preferred? Does any material go to waste?
6. Is battery recycling profitable?

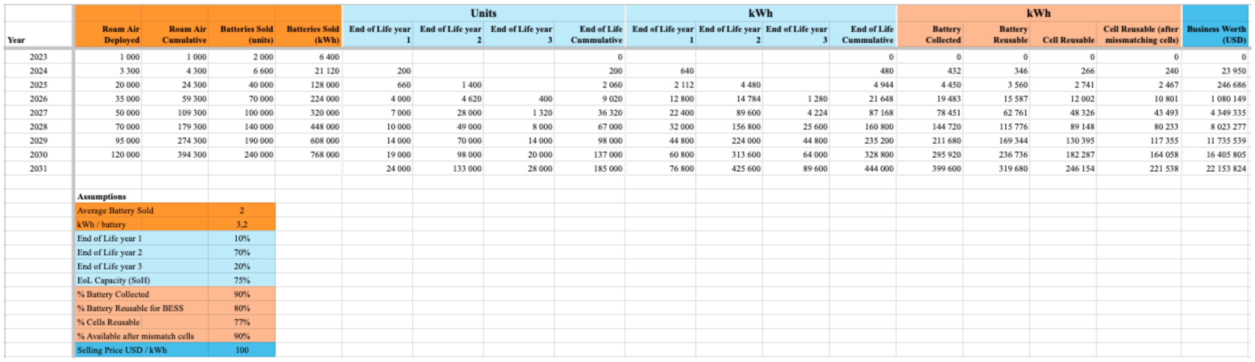
9.2 Appendix B: Cost Comparison Calculations

The appendix presents an overview of the estimated EoL Roam Air EVBs, given the growth scenario for pack- and cell-level respectively, as well as the cost comparison model made in Google Sheets.



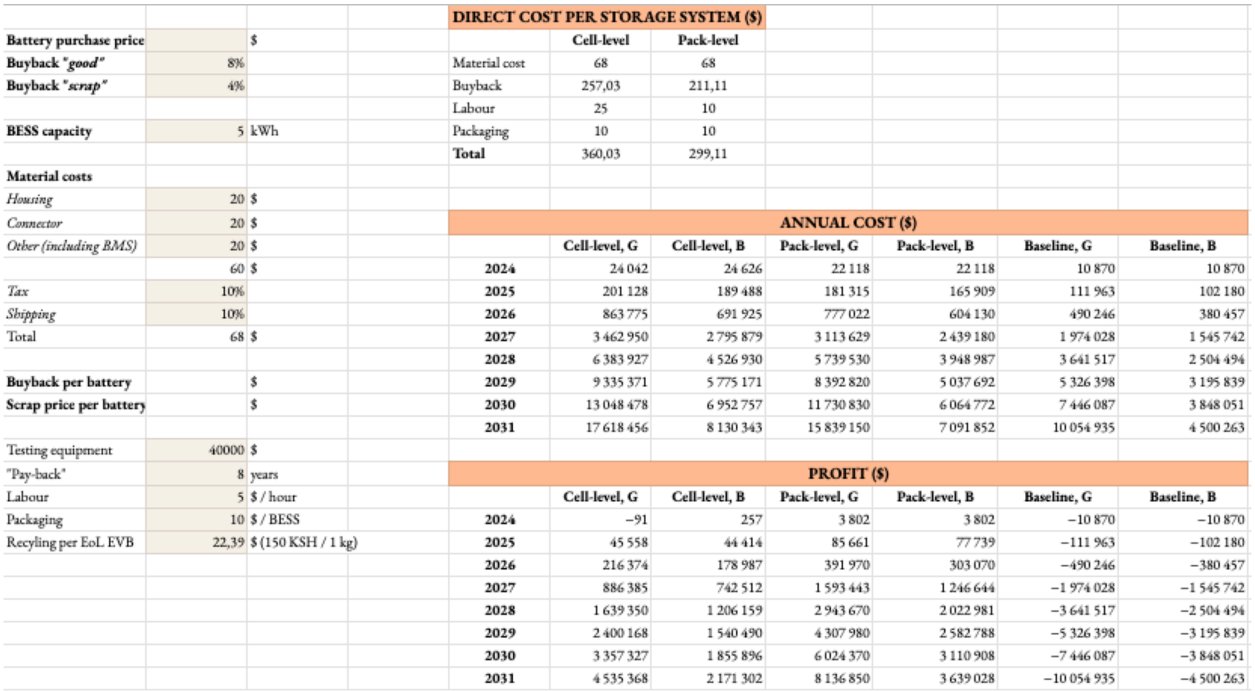
					Units				kWh						
Year	Roam Air Deployed	Roam Air Cumulative	Batteries Sold (units)	Batteries Sold (kWh)	End of Life year 1	End of Life year 2	End of Life year 3	End of Life Cummulative	End of Life year 1	End of Life year 2	End of Life year 3	End of Life Cummulative	Battery Collected	Battery Reusable	Business Worth (USD)
2023	1 000	1 000	2 000	6 400				0				0	0	0	0
2024	3 300	4 300	6 600	21 120	200			200	640			480	432	259	25 920
2025	20 000	24 300	40 000	128 000	660	1 400		2 060	2 112	4 480		4 944	4 450	2 670	266 976
2026	35 000	59 300	70 000	224 000	4 000	4 620	400	9 020	12 800	14 784	1 280	21 648	19 483	11 690	1 168 992
2027	50 000	109 300	100 000	320 000	7 000	28 000	1 320	36 320	22 400	89 600	4 224	87 168	78 451	47 071	4 707 072
2028	70 000	179 300	140 000	448 000	10 000	49 000	8 000	67 000	32 000	156 800	25 600	160 800	144 720	86 832	8 683 200
2029	95 000	274 300	190 000	608 000	14 000	70 000	14 000	98 000	44 800	224 000	44 800	235 200	211 680	127 008	12 700 800
2030	120 000	394 300	240 000	768 000	19 000	98 000	20 000	137 000	60 800	313 600	64 000	328 800	295 920	177 552	17 755 200
2031					24 000	133 000	28 000	185 000	76 800	425 600	89 600	444 000	399 600	239 760	23 976 000

Assumptions	
Average Battery Sold	2
kWh / battery	3,2
End of Life year 1	10%
End of Life year 2	70%
End of Life year 3	20%
EoL Capacity (SoH)	75%
% Battery Collected	90%
% Battery Reusable for BESS	60%
Selling Price USD / kWh	100



					Units				kWh				kWh				
Year	Roam Air Deployed	Roam Air Cumulative	Batteries Sold (units)	Batteries Sold (kWh)	End of Life year 1	End of Life year 2	End of Life year 3	End of Life Cummulative	End of Life year 1	End of Life year 2	End of Life year 3	End of Life Cummulative	Battery Collected	Battery Reusable	Cell Reusable	Cell Reusable (after missmatching cells)	Business Worth (USD)
2023	1 000	1 000	2 000	6 400				0				0	0	0	0	0	0
2024	3 300	4 300	6 600	21 120	200			200	640			480	432	346	266	240	23 950
2025	20 000	24 300	40 000	128 000	660	1 400		2 060	2 112	4 480		4 944	4 450	3 560	2 741	2 467	246 686
2026	35 000	59 300	70 000	224 000	4 000	4 620	400	9 020	12 800	14 784	1 280	21 648	19 483	15 587	12 002	10 801	1 080 149
2027	50 000	109 300	100 000	320 000	7 000	28 000	1 320	36 320	22 400	89 600	4 224	87 168	78 451	62 761	48 326	43 493	4 349 335
2028	70 000	179 300	140 000	448 000	10 000	49 000	8 000	67 000	32 000	156 800	25 600	160 800	144 720	115 776	89 148	80 233	8 023 277
2029	95 000	274 300	190 000	608 000	14 000	70 000	14 000	98 000	44 800	224 000	44 800	235 200	211 680	169 344	130 395	117 355	11 735 539
2030	120 000	394 300	240 000	768 000	19 000	98 000	20 000	137 000	60 800	313 600	64 000	328 800	295 920	236 736	182 287	164 058	16 405 805
2031					24 000	133 000	28 000	185 000	76 800	425 600	89 600	444 000	399 600	319 680	246 154	221 538	22 153 824

Assumptions	
Average Battery Sold	2
kWh / battery	3,2
End of Life year 1	10%
End of Life year 2	70%
End of Life year 3	20%
EoL Capacity (SoH)	75%
% Battery Collected	90%
% Battery Reusable for BESS	80%
% Cells Reusable	77%
% Available after mismatch cells	90%
Selling Price USD / kWh	100



Battery purchase price		$
Buyback "*good*"	8%	
Buyback "*scrap*"	4%	
BESS capacity	5	kWh
Material costs		
Housing	20	$
Connector	20	$
Other (including BMS)	20	$
	60	$
Tax	10%	
Shipping	10%	
Total	68	$
Buyback per battery		$
Scrap price per battery		$
Testing equipment	40000	$
"Pay-back"	8	years
Labour	5	$ / hour
Packaging	10	$ / BESS
Recyling per EoL EVB	22,39	$ (150 KSH / 1 kg)

DIRECT COST PER STORAGE SYSTEM ($)		
	Cell-level	**Pack-level**
Material cost	68	68
Buyback	257,03	211,11
Labour	25	10
Packaging	10	10
Total	360,03	299,11

ANNUAL COST ($)						
	Cell-level, G	**Cell-level, B**	**Pack-level, G**	**Pack-level, B**	**Baseline, G**	**Baseline, B**
2024	24 042	24 626	22 118	22 118	10 870	10 870
2025	201 128	189 488	181 315	165 909	111 963	102 180
2026	863 775	691 925	777 022	604 130	490 246	380 457
2027	3 462 950	2 795 879	3 113 629	2 439 180	1 974 028	1 545 742
2028	6 383 927	4 526 930	5 739 530	3 948 987	3 641 517	2 504 494
2029	9 335 371	5 775 171	8 392 820	5 037 692	5 326 398	3 195 839
2030	13 048 478	6 952 757	11 730 830	6 064 772	7 446 087	3 848 051
2031	17 618 456	8 130 343	15 839 150	7 091 852	10 054 935	4 500 263

PROFIT ($)						
	Cell-level, G	**Cell-level, B**	**Pack-level, G**	**Pack-level, B**	**Baseline, G**	**Baseline, B**
2024	−91	257	3 802	3 802	−10 870	−10 870
2025	45 558	44 414	85 661	77 739	−111 963	−102 180
2026	216 374	178 987	391 970	303 070	−490 246	−380 457
2027	886 385	742 512	1 593 443	1 246 644	−1 974 028	−1 545 742
2028	1 639 350	1 206 159	2 943 670	2 022 981	−3 641 517	−2 504 494
2029	2 400 168	1 540 490	4 307 980	2 582 788	−5 326 398	−3 195 839
2030	3 357 327	1 855 896	6 024 370	3 110 908	−7 446 087	−3 848 051
2031	4 535 368	2 171 302	8 136 850	3 639 028	−10 054 935	−4 500 263