A Techno-Economic Evaluation of Repurposing Retired Electric Vehicle Batteries in Off-Grid EV Charging Stations in Kenya

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Declaration and Approval

Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself.

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Abstract

Urban air pollution is becoming a major environmental and public health issue in Kenyan cities; thus, Kenya has taken great steps in policy development to reduce automobile emissions. A major step towards the achievement of this goal is through adoption of electric mobility. Battery-powered EVs are becoming a predominant technology worldwide, including in Kenya. These vehicles and the global transition to electric mobility have spurred studies on EV battery manufacture, battery technology, and end of life management.

This research has reviewed end-of-life EV batteries through a second use application in energy storage and charging support in off-grid EV charging stations. This was achieved through estimating the volumes of batteries that will be available for second life application by 2030. Further, the economic implications of reusing EV batteries in ESS and charging support for off-grid charging stations were studied.

The research concluded that there would be a sufficient volume of second life batteries in Kenya in the next 15 years for use in secondary applications, including off-grid EV charging stations. The electric motorcycles were particularly visible as their adoption trends showed potential to grow rapidly unlike the motor vehicles hence the need to commit further research to identifying potential reuse and repurposing pathways, especially due to their lower battery capacities. The number of registered EVs in Kenya is anticipated to reach 55,199 in 15 years, an estimate from the CAGR projections of 3.39% for motorcycles and (4.68%) for passenger vehicles. Further the volume of expired EV batteries available for reuse is estimated to reach 102,512kWh.

The study further investigates the economic prospects of an off-grid EV charging station with an ESS utilizing second life batteries and concludes that the venture is expected to have a BESS lifespan of 4 years. In addition, the price of a SLB pack was computed to give the best NPV at 16.65USD per kWh further highlighting the need to lower the price of second life batteries through government incentive schemes that promote their use in secondary applications. In addition, the state of health of the battery is determined as a significant factor in the computation of the second life battery cost.

Keywords: End of life battery**,** Energy Storage Systems, Electric Vehicle, Second-Life Battery, State of Health

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List of Abbreviations

AC	Alternating current
BESS	Battery Energy Storage System
BMS	Battery Management System
BSS	Battery Swapping Station
CAPEX	Capital expenditure
DC	Direct current
DoD	Depth of Discharge
E-MSP	Electric Mobility Service Provider
EOL	End of life
EPRA	Energy and Petroleum Regulatory Authority
ESS	Energy Storage Systems
EV	Electric Vehicle
EVB	Electric Vehicle Battery
GST	Goods and Services Tax
LCOS	Levelized cost of storage
NACOSTI	National Commission for Science, Technology and Innovation
NPV	Net Present Value
OEM	Original Equipment Manufacturers
OPEX	Operational expenditure
PCS	Public Charging Station
PSV	Public Service Vehicle
SLB	Second Life Battery
SOH	State of Health

Definition of Terms

End of life	The electric vehicle battery is said to have reached end of life when it can no longer store sufficient power to attain the design vehicle range or speed before it requires to be charged. This is usually once the battery has attained 70% to 80% of its design capacity (Mathews et al., 2020).
Electric Vehicle Battery	These are rechargeable batteries used to power the electric motors in battery electric vehicles or hybrid electric vehicles, characteristically made up of lithium-ion chemistry (Hendawi et al., 2022).
Levelized cost of storage	This metric quantifies the discounted cost per unit of discharged electricity for a specific storage technology and application. It accounts for all technical and economic parameters affecting the lifetime cost of discharging stored electricity (Schmidt et al., 2019).
Net Present Value	The cost of an investment throughout its lifetime discounted to its value today (Al-Alawi et al., 2022). It is used to determine if an investment will be profitable within its lifetime while making investment decisions.
Second Life Battery	This is a battery that has reached end of life in their first use, but still have sufficient capacity to be useful in a less energy intensive application (Kebir et al., 2023).
State of Health	A measure that indicates the level of degradation and remaining capacity of a battery. It distinguishes between a new battery and state of a used battery, as a percentage of its initial capacity (Mathews et al., 2020).

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Chapter 1: Introduction

1.1 Background to the Study

The global energy landscape is evolving towards sustainable energy use and net zero emission goals, in line with the Paris Agreement of 2015 Gomez-Echeverri, (2018), reduce reliance on fossil fuels, with electric vehicles (EVs) becoming increasingly prominent and Kenya is no exception (Galuszka et al., 2021). Environmental concerns, government incentives, infrastructure development, and cost reductions drive this growth. EVs reduce greenhouse gas emissions and improve air quality (Choi & Rhee, 2020).

Kenya's national determined contribution (NDC) pledges to cut greenhouse gas (GHG) emissions by 30% by 2030 (Al-Guthmy & Yan, 2019). The Kenyan government's low-carbon urban development strategy to offer a clean, safe, reliable, efficient, and economical public transport system is one of the primary mitigation steps to reduce GHG emissions. Elimination of Kenya's ageing fleet of petrol and diesel PSVs, and replacement by electric vehicles (EVs) with lower operational and maintenance costs than ICE vehicles could provide a cleaner, cheaper alternative for the anticipated 30% increase in public passenger transit. This is enticing because hydropower, geothermal, and wind generate most of Kenya's grid electricity. EVs are a low-carbon transportation alternative that could reduce GHG emissions, as the electricity generation mix becomes less carbon intensive.

The Kenya National Bureau of Statistics (KNBS) estimates that as of 2022, there were 1,350 registered EVs in Kenya, out of a total of 4.4 million registered vehicles (Lore & Baragu, 2023). These electric vehicles come in a range of models, including fully electric models and hybrid options (Sanguesa et al., 2021). The lifespan of electric vehicle batteries is projected to be several hundred thousand kilometers before replacement Koroma et al., (2022); making battery management technologies that improve performance and lifespan crucial. Under ideal charging and operating conditions, electric car batteries last 8–12 years (Zhao et al., 2021). Since Kenya's fleet consists predominantly of used cars with 80% of registered vehicles being second hand. It is imperative to provide strategies to reuse or recycled batteries in second hand EVs after a few years (Knöll et al., 2021). Efficiency in reuse and recycling can extend the life of used batteries while providing an income. Attempts to manage the EV industry include the Kenya's national e-mobility draft policy, released in March 2024 that governs EV importation, charging infrastructure, and end-of-life battery management.

1.2 Problem Statement

The transition to e-mobility in Kenya presents two challenges, which have been discussed in this research, which are insufficient EV charging infrastructure and the management of end of first life batteries. In this study, the challenge of accumulation of disused EV batteries has been investigated and the proposed reuse in EV charging stations as energy storage systems for EV charging support before eventual recycling or disposal. This is suggested as a means to effectively manage EV batteries in their second life, whilst expanding the EV charging infrastructure especially for off-grid locations.

From the findings of this research, it is projected that an economically feasible solution for development of off-grid EV charging stations, in an effort to address the existing gap of EV charging infrastructure, which is an impediment to wide adoption of EVs in Kenya. This conclusion has been reached following a review of various case studies where second life batteries have been used for applications in grid ancillary services (Lee et al., 2021), off-grid solar and wind EV charging stations (Ramanan et al., 2023) as well as in commercial and domestic power applications (Kebir et al., 2023) with various degrees of achievement.

The study however had its limitations in the technical parameters under analysis including failure to model the remaining useful life more accurately with assumptions made of degradation at the rate of 4.7% per year based on semi-empirical data from research (Vignesh et al., 2024). In addition, the indicators contributing to battery SOH, charge density, power density and battery operating parameters were not adequately studied in the technological analysis. The research could not base its findings on experimental data hence semi-empirical data has been used in the computation of second life battery cost estimates. The study findings also fail to show how the incentivization model will benefit the EV owner since there has been no linkage on implementation of the model to the recommended buy back scheme for the battery owner.

The study findings suggests that there will be an adequate volume of 67,029kWh of retired EV battery capacity in the next 15 in Kenya to be utilized for second life applications. These would be available for reuse in applications including off-grid charging stations. The proposed incentivization model should offer a policy direction in developing a business model for the purchasing and sale of second life batteries through EV OEMs and dealers to facilitate transfer of the batteries from the EV owners to the battery purchasers.

1.3 Research Objectives

1.3.1 General Objective

The objective of this research was to evaluate the viability of repurposing EV batteries for adoption as battery energy storage systems in the implementation of off-grid solar powered EV charging stations.

1.3.2 Specific Objectives

i. To estimate the number of degraded EV batteries that will be available for repurposing in Kenya in the next 15 years.
ii. To estimate the repurposing cost of an EV battery and estimate the benefit per unit of repurposed batteries using statistical analysis.
iii. To calculate the Levelized cost of storage (LCOS) when using the repurposed battery in comparison to installation of a new battery.
iv. To develop an incentivization model to lower the cost of purchasing a repurposed EV battery.

1.4 Research Questions

This research aims to explore the technical and economic aspects of the EV charging infrastructure by use of repurposed second life EV batteries for energy storage in off-grid solar powered EV charging stations. The research questions will include,

i. How many retired electric vehicle batteries will be available in Kenya in the next 15 years?
ii. What would be the cost of repurposing these EV batteries for second- life application?
iii. What would be the benefit of using a second life EV battery in comparison to a new battery?
iv. What is the levelized cost of storage of the repurposed battery?
v. What would be the impact of incentives on the cost of a repurposed EV battery?

These research concerns can serve as the foundation for a thorough examination of the techno-economic landscape in Kenya's transition to e-mobility with respect to retired EV battery management in the area of battery reuse. They cover a wide range of second life battery reuse concerns and can assist lead research into developing viable solutions and recommendations for stakeholders in Kenya's e-mobility sector with a focus to applications on repurposed EV batteries.

1.5 Justification

Kenya's transition to e-mobility is a significant step towards sustainability, energy security, and environmental protection. This research aims to address key questions in Kenya's Draft National E-mobility Policy, (2024) by investigating the most economically and technically viable battery waste management pathways for electric vehicles, considering the rising demand for EVs in the country. This was achieved through assessment of the current state of e-mobility in Kenya, forecasting EV uptake and subsequent lithium-ion battery availability, investigating existing e-waste management systems and simulating various retired EV battery management pathways through repurposing to compare their economic feasibility and environmental impact. In order to provide a comprehensive assessment on the future waste battery stream, this study will be primarily focused on lithium-ion batteries as they are currently the most economically and technologically viable battery option for electric vehicles, with alternative battery technologies still being in experimental stages or not yet available for commercial purchasing. The findings and recommendations of this research will be vital in positioning Kenya as a pioneer in sustainable transportation innovation and contributing to global climate change mitigation efforts. Thus, will be beneficial not only for Kenya but for other developing countries who are seeking to establish a sustainable waste management system for EV batteries through repurposing.

1.6 Scope

The technical and economic assessment of second-use EV batteries through reclamation and energy storage for off-grid charging stations was done. Initial material flow models for Kenya's lithium-ion battery ecosystem defined system limits and identified reuse quantities. Published experimental studies and modeling investigations were used to explore technical parameters such initial battery SOH at end of life.

EV charging demand and expired EV battery availability for secondary use were analyzed in the technical study. A cost and benefit evaluation of initial capital expenditure, operational expenses, and long-term profitability of second-life battery use was done in the economic assessment. It estimated break-even points and return on investment for reconditioned batteries using battery SOH between 50% and 80%. When evaluating pricing scenarios, a reused battery costing model considered incentivization conditions between 0% and 15% on cost estimations. In the absence of significant historical data on electric vehicle batteries and their repurposing methods, the scope was defined using related use cases in published research. Research-based assumptions and conclusions have drawn with the study limitations contributing to recommendations for further technical analysis, longitudinal investigations, and regional comparisons.

1.7 Limitations

The research on technical and economic evaluation of retired EV battery repurposing as ESS in off-grid EV charging stations had scope gaps in the selection of technical parameters under analysis including failure to model the remaining useful life more accurately with assumptions made of degradation at the rate of 4.7% per year based on semi-empirical data from research (Vignesh et al., 2024). In addition, the indicators contributing to battery SOH, charge density, power density and battery operating parameters were not adequately studied in the technological analysis. Adequacy of the research in terms of experimental evaluation of techno-economic review could not be achieved hence most of the computations were based on semi-empirical data from similar research obtained through case study reviews. The study findings also fail to show how the incentivization model will benefit the EV owner since there has been no linkage on implementation of the model to the recommended buy back scheme for the battery owner.

1.8 Report Organization

This dissertation comprises five chapters. The initial chapter presents the foundational considerations that informed the decision to pursue this research, addressing the context, the problem to be addressed, the objectives, hypotheses, and inquiries to be explored, the significance of the research, the study's scope, and its limitations. The second chapter emphasizes diverse research and case studies pertinent to this investigation, through observations conducted in numerous cities and countries, identifying parallels in the conclusions from these studies. The third chapter delineates the methodology employed in the study, providing a comprehensive account of data collecting and analysis, model construction, and specifically detailing the presentation of results, culminating with the ethical considerations addressed in the research. The fourth chapter delineates the research findings, examining the technical and economic contributions of the study, and concludes with validation derived from case studies of similar research. The final chapter presents the conclusion, recommendations, and suggestions for future research, specifically addressing the limitations of this study. The report is concluded with relevant references and appendices.

Chapter 2: Literature Review

2.1 Introduction

This chapter gives an overview of research and published information related to EV batteries. This will include a general overview of EVs, batteries and components and repurposing second life electric vehicle batteries for e-mobility applications, particularly in EV charging. It also examines global regulations for EV charging stations and identifies research gaps from similar research for future studies.

2.2 Theoretical Review

2.2.1 The Fundamentals of EVs and EV Batteries

Electric vehicles (EVs) have become popular as a result of global warming and fossil fuel depletion (“A Review of Electric Vehicle Technologies,” 2020). EVs use energy storage units to power electric motors. Due to the cost, sizing, management, energy, and power density constraints of conventional energy storage systems, an energy-generating unit is needed. With research and innovation, in modern power electronics EVs have become more energy efficient.

Electric vehicles come in a range of models, including fully electric models and hybrid options (Sanguesa et al., 2021). The market offers various categories of electric vehicles, including Battery Electric Vehicles (BEVs), which utilize batteries for storage and charge through electric energy sourced from external power supplies. Hybrid Electric Vehicles (HEVs) employ a synergy between an internal combustion engine and a battery, with the latter being charged via regenerative braking. Plug-in Hybrid Electric Vehicles (PHEVs) combine an engine with a battery that can be charged from an electric power source, while Fuel Cell Vehicles generate electricity on board.

Lithium-ion batteries are the preferred choice among vehicle manufacturers due to their high energy density, efficiency, and temperature performance. Different metal oxide cathodes in lithium-ion batteries have distinct performance and cost trade-offs. Nickel cobalt aluminum (NCA), nickel manganese cobalt (NMC) and lithium iron phosphate (LFP) are the most often utilized chemistries in electro mobility applications (Narang et al., 2023).

2.2.2 The Science of Repurposing Batteries

Electric vehicle battery volumes continue to increase globally, and the aspects of a circular economy become vital. Circularity is an ecosystem that recycles and regenerates materials and products (Goyal et al., 2023). (Grossman et al., 2023) opines that reusing batteries has broader environmental justice implications, since it extends their lifespan and delays dismantling, smelting, and refining, making it the most cost-effective and ecological choice. Degraded batteries can be used in energy storage and industrial applications (Al-Alawi et al., 2022). Reusing EV batteries can be implemented using two methods. The first technique entails treating the battery pack as a single unit and just performing visual and electrical tests. The second technique involves disassembling and testing individual battery modules or cells, then assembling them to create a new battery that fits the needs of the second-life application as presented by (Rallo, Benveniste, et al., 2020). The former strategy involves direct reuse, whereas the later involves reconditioning. Second-life EV batteries must be tested and reconfigured for stationary use. The degree of these procedures depends on consumer needs and preferences, since batteries can be configured in different ways.

EV batteries reach the end of their lifespan as primary batteries when they reach 70-80% of their capacity (Hossain et al., 2019). This decline is expected after five to eight years of use or 100,000 miles (160,000 kilometers) of travel (Nazaralizadeh et al., 2024). Although decommissioned, electric vehicle (EV) batteries can still be used in residential households or to manage power supply fluctuations in large-scale photovoltaic (PV) plants (Martinez-Laserna et al., 2018). As sustainable investments, EVs are expected to last 7-10 years before reaching EOL(Haram et al., 2021; Hossain et al., 2019).

2.2.3 Forecasting Methods

Decision-making and planning have traditionally prioritized forecasting. People and organizations are excited and challenged by future uncertainty, trying to minimize risks and maximize benefits (Petropoulos et al., 2022). The complexity of forecasting applications requires a variety of methodologies to solve real-world problems. Forecasting or distributing an uncertain number often involves professional advice or algorithmic methods. Academic disciplines occasionally disagree on algorithmic techniques, and how to combine algorithmic forecasts with human expertise (Zellner et al., 2021). As a factor of limited data for this research in Kenya, trends have been reviewed and advised on the forecasting of future trends in the e-mobility sector as a factor of transport trends globally and locally in Kenya. The accuracy of the projection methodology may be subject to further modification as the trends continue to evolve.

2.2.4 Financial Feasibility Analysis

The business feasibility study will entail an understanding of commercial, environmental, technical, risk and economic factors. Economic factors which include the measure of profitability, market share, and competition cannot be overemphasized during planning for commercialization of an idea (Dewanti et al., 2022). This research has utilized the criteria of net present value (NPV), benefit to cost ratio (B/C), payback period (PBP) and levelized cost of storage (LCOS) to determine the economic viability of an investment in the proposed solution of an off-grid PV charging station with reused EV batteries as an ESS.

The financial value of the business can only be realized through assessment of the cash flow where future profitability of the venture must be greater than capital expensed (NPV). The time of the capital turning point (PBP), the benefits must be greater than the value of the investment (B/C). Energy investments incorporate the metric to determine the discounted total lifetime cost of a storage technology divided by the discounted total energy discharged from the system. These criteria are useful in assessing the financial feasibility of a business as a form of opportunity analysis and providing anticipation of risks to running a business ("Techno-Economic Feasibility Study Methods in Startup Financing," 2021).

2.2.5 Incentive Schemes

Economic incentives are monetary rewards used to modify consumption and production behaviors within the economy. Incentive schemes are financial mechanisms that offer tax exemptions, allowances, or benefits, including tax credits, allowing a part of the investment cost in authorized technology to be utilized to reduce tax liabilities (*Economic Incentives: Meaning, Types, Advantages, Disadvantages & Uses*, 2025). Tax incentives can positively influence emerging, innovative technology. Facilitating regular revisions to the list of qualified measures enables the schemes to enhance the market launch phase of innovative technologies. This research considered a second life EV battery purchase price model, which incorporated a discount factor to estimate the cost of the battery under various discount conditions as presented in a research by (Rallo, Benveniste, et al., 2020).

2.3 Empirical Review

This section of the research presents global EV industry trends, highlighting the research on EV battery management practices, standards, policies and research limitations. These have contributed to the technical and economic evaluation of the BESS. Table 2.1 summarizes similar research, their con

Table 2. 1: Published research on repurposing of second life EV batteries

SN	Title	Contribution and research gap
1	Current status and perspectives on recycling of end-of-life battery of electric vehicle in the Republic of Korea (Choi & Rhee, 2020)	Highlights South Korea's attempts to handle end-of-life (EOL) batteries in electric vehicle (EV) battery recycling. Similar to ICE vehicle, the authors suggest an Extended Producer Responsibility (EPR) scheme for EOL EV batteries to assure recycling and resource recovery. To address EOL EV battery recycling difficulties in South Korea, this study emphasizes comprehensive policies and international cooperation. Although EPR systems are suggested, battery recycling regulations and incentives are lacking. Hazardous EOL batteries require research on safe collection, storage, and transportation. Cost-benefit analysis and secondary raw material market development are vital to assess recycling economics.
2	Life cycle assessment of battery electric vehicles: Implications of future electricity mix and different battery end-of-life management Koroma et al., (2022)	The future electricity mix, and battery end-of-life management are among the study's research gaps. Recommends further research on battery refurbishing and second-life applications' environmental benefits. This requires more thorough life cycle assessments (LCAs) that integrate data across geographies and account for multiple environmental effect categories. Such research can explain BEV sustainability holistically. For consistency and dependability in BEV environmental impact assessments, the study recommends LCA standardization with balance system boundaries, impact categories, and data sources.
3	Second-life battery systems for affordable energy access in Kenyan primary schools. (Kebir et al., 2023)	The research examines how second-life lithium-ion batteries and solar photovoltaics can offer economical and reliable energy to Kenyan primary schools. The study emphasizes the necessity for longitudinal research on second-life battery performance and degradation in off-grid situations. Understanding how these batteries age in different environments is essential for reliability and cost-effectiveness.

		Notes non-standardized techniques exist for testing second-life battery health and appropriateness for various applications. Standardizing second-life battery testing and certification would improve consistency and safety. Propose research to assess such systems' scalability across regions with differing infrastructure and economies. This includes evaluating supply chain dynamics and cost variations. Examine how second-life battery systems might be integrated into national and local energy infrastructures. This would help determine hybrid system potential and energy reliability and cost. The research emphasizes the need for supportive laws and regulations to promote second-life battery systems. This includes clear battery sourcing, usage, and disposal criteria and incentives for players in such technology.
4	Growth of Battery Swapping in EV Passenger Car Segments in India. Sankaran & Venkatesan, (2022).	Research shows that the lack of standardized battery packs among OEMs hinders battery replacement scalability. Universal battery design and interface standards are essential for interoperability and infrastructure cost reduction. An extensive battery-swapping network requires significant expenditure. Research on ideal sites, cost-effective designs, and efficient operational models is needed to make these stations viable and accessible. Comprehensive regulatory recommendations for battery-swapping ecosystem players must cover safety, cost, and incentives. Consumer adoption methods can be gathered from convenience, cost, and trust studies. While battery swapping may lower EV prices, its long-term environmental impact, including battery life cycle and recycling, must be assessed for sustainability.
5	Fast charging stations with stationary batteries: A techno-economic comparison of fast charging along highways and in cities (Funke et al., 2020)	The techno-economic implications of integrating stationary batteries into highway and urban rapid charging stations for electric cars (EVs) is examined. Due to heavy use, intraday trading can impair highway station battery life, suggests the study, recommending further research to reduce battery degradation in high-demand conditions.

		Second-life batteries boost system profitability; however further economic assessments are needed to determine the long-term cost benefits and drawbacks of using second-life batteries in fast charging stations. The study examines battery technologies but does not look at stationary storage system sizing and setup for different use cases. The most efficient and cost-effective charging configurations need more research. This study does not examine how integrating stationary storage devices with renewable energy sources like solar or wind could lower costs and environmental effect. Such interfaces should be studied for feasibility and benefits. The analysis fails to highlight policies and regulations that could affect rapid charging stations with stationary batteries. Research into supportive policies and laws is crucial for widespread technology adoption.
6	Are electric vehicle batteries being underused? A review of current practices and sources of circularity. Etxandi-Santolaya et al., (2023)	The study analyzes the underuse of electric vehicle (EV) batteries and indicates further research needed to improve their circularity and sustainability. Current practices set a battery's EoL at 70–80% SOH, regardless of performance or application. This may prematurely retire batteries with a long lifespan. Suggests functional EoL assessment using real-world performance and application-specific criteria. The lack of standard battery health and performance data makes EoL assessment difficult. For consistent battery reuse and recycling assessment and decision-making, uniform diagnostic tools and methods are needed. By letting EV batteries send power to the grid, vehicle to grid (V2G) technologies offer a promising alternative to second-life applications. Optimizing V2G systems' economic viability, technical integration, and legal frameworks needs more research. Battery deterioration parameters like charging cycles, temperature, and usage patterns are poorly understood, hence more research is required to understand these pathways and

		discover ways to reduce degradation, increasing battery life and improving sustainability. Policy and economic incentives for battery reuse, refurbishing, and recycling are lacking. The EV battery sector needs cost-benefit evaluations, market dynamics, and supportive policy research to promote circular economy practices.
7	Lithium-ion battery 2nd life used as a stationary energy storage system: Ageing and economic analysis in two real cases (Rallo, Canals Casals, et al., 2020).	The study shows the lack of standardized SOH assessment methodologies for EV batteries. Universal diagnostic tools and processes are needed for safer second-life evaluation and deployment. Maximizing SESS battery life requires understanding how cycling patterns, temperature fluctuations, and load profiles affect battery life and degradation patterns. This study analyzes specific possibilities in Spain, but more comprehensive economic models that account for different areas, power markets, and regulatory settings are proposed. These models should consider energy arbitrage, auxiliary services, and prospective income streams to evaluate second-life battery systems' financial sustainability. First-life EV BMS may not be suited for second-life stationary storage. SESS safety and efficiency require research into second-life battery BMS to handle voltage imbalance, thermal management, and state-of-charge balancing. The report underlines the lack of specific regulations for stationary EV battery reuse. Comprehensive policies and standards to ensure safety, performance, and environmental compliance, enabling second-life battery system adoption are proposed.

2.4 Summary of Gaps in Literature

With the growing research in EV battery secondary use applications, the research gaps from similar research are presented in Table 2.1 summarized as follows,

A lack of standardization of battery health assessment. A methodological framework for calculating a functional end of life approach should be investigated and presented to fill these research gaps and improve recycling end of life estimates. The aging process of first- and second-life batteries and battery SOH characteristics to determine suitable applications must be studied as application in energy storage systems increase.

Regulatory and policy frameworks that support second life EV battery applications in circular practices. The regulatory space is still in infancy as the disused batteries continue to become available for reuse. There have not been standards developed to guide the repurpose applications for secondary use batteries, which provide for safety especially in collection, transportation and remanufacturing for reuse. Further research with an aim to achieve standardization in these practices is proposed.

EV batteries are designed to function with specified BMS in specific vehicle models with specific manufacturer setups. Its designs are independent of the first EV application because the BMS collects battery data. Although retired batteries are reused, there is no BMS built for secondary use applications independent of the first life. This gap necessitates a study of BMS solutions for battery reuse to integrate with existing energy systems. Manufacturer collaborations can promote data sharing and collaborations across the recycled battery value chain to spur innovation, investment, and lifetime evaluations.

Cost uncertainties, extensive economic modeling and feasibility studies for multiple reuse applications and conditions, and a limited understanding of diverse degeneration processes complicate regrouping retired EV batteries for secondary purposes. This makes it difficult to accurately cost second-life batteries in varied settings. A unified system to cost reused batteries can be improved through research.

For optimization of sizing and configurations for secondary applications, future research should evaluate the capacity needs of various drivers under different environmental conditions, study the increase in internal resistance that limits battery power, and address safety-related aspects. The studies also suggest further research on standardization of second-life battery designs and the development of standards for second-life batteries and regulatory frameworks to ensure quality, longevity and circular approaches in their application.

2.5 Conclusion

This chapter shows its significance in the dissertation where it highlights various aspects of second life battery management research globally. It has brought to light the significant aspects in the design and operationalization of second life EV battery applications, challenges and existing gaps that can be addressed through research. I addition case studies and similar research have been used to investigate the applicability of second life batteries in EV charging stations highlighting successes and gaps in these applications. These have been useful in the design of this research.

Chapter 3: Methodology

3.1 Introduction

This research provides a techno-economic analysis of second-life electric vehicle batteries in Kenya, aimed at repurposing in off-grid EV charging stations. The study assesses the availability through material flow analysis, cost implications and potential economic opportunities for second life EV battery use in ESS in EV charging stations.

With the global expanding EV market, the impending influx of second life batteries poses significant challenges and opportunities for the region's sustainability and economic objectives (Galuszka et al., 2021). This case study investigates Kenya's current EV battery second- life landscape, analyzing the technical operational practices, and market conditions influencing battery disposal and repurposing.

3.2 Research Design

A research design refers to the overall strategy, which outlines the systematic processes, methods, and procedures followed in conducting a research study. This study has adopted a quantitative analysis research design. The research integrated quantitative research techniques through data analysis to provide a perspective on the research questions at hand. This approach delivers objective, quantifiable, and reproducible data that becomes the foundation for assessing the technical efficacy and economic viability of a technology or system using data and study variables (Devi, 2017). (Creswell, 2009) characterizes quantitative research as a methodical and rigorous approach to comprehending relationships and results via numerical data, rendering it indispensable for study domains that emphasize measurement, prediction, and generalization.

Previous studies on the research topic presented in section 2.3 have been carried out through investigations of various parameters and scenarios. The research methodologies employed in these studies have been captured for comparison. A summary of the methods, their strengths and weaknesses are presented in Table 3.1

Table 3. 1 Previous Methods, their strengths and weaknesses

SN	Research Method	Strength	Weakness
1	Techno-Economic modeling and simulation (Rallo, Canals Casals, et al., 2020)	Analysis of system performance over time. Facilitates scenario analysis under diverse conditions and investigates different parameters simultaneously. Enhances the optimization of operational conditions.	The correctness of a model depends on research assumptions and input data quality. Variables are dependent on the researcher and may not entirely incorporate real-world complexities and uncertainties. Demands ongoing revisions to align with technical progress and market fluctuations.
2	Optimization models (Wangsupphaphol et al., 2023)	Enhances decision-making in real-time operations through improving system efficiencies and eliminates error from variations in fluctuating conditions. Cost efficiencies in the models developed.	Complexity in model formulation and execution, with demanding computational resources. Accuracy of the model relies on the caliber of input data and the assumptions of the model.
3	Cost-Benefit Analysis (CBA) models (Kampker et al., 2023)	Offers a transparent financial assessment of project feasibility. Simplifies studies aimed at concept development for funding acquisition by illustrating economic returns. Enables economic comparison of different energy storage options.	Vulnerable to assumptions about forthcoming energy costs and battery efficacy. May disregard non-financial advantages, including social and environmental effects. Excludes externalities such as policy alterations or market fluctuations.
4	Life Cycle Assessment (LCA) (Koroma et al., 2022)	Facilitates sustainable decision-making by identifying opportunities for enhancement considering environmental performance. It is possible to compare various battery chemistries and technology.	Characterized by a high volume of data necessitating access to confidential information. Outcomes may differ according on geographical and temporal circumstances. May not encompass all indirect environmental repercussions.

5	Material Flow Analysis (MFA) (Lieskoski et al., 2024)	Offers insights into resource availability and possible constraints. Aids in strategizing prospective supply and demand situations making it possible to make strategic supply chain decisions.	It necessitates extensive information regarding material movements and inventories. Assumptions about recycling rates can profoundly affect results since unmonitored recycling efforts may not be considered.

3.3 Case Study Description

The research primarily studied e-mobility adoption within Kenya. By investigating EV registration trends, EV charging demand and economic analysis of setting up an off-grid EV charging station with repurposed EV batteries as an ESS.

Employing a quantitative research approach, the study triangulates secondary data from transport and energy agencies, analysis of current battery reuse strategies, and simulation of second life cost scenarios through the parameters of levelized cost of storage and net present value to determine the optimal cost for purchasing second life batteries for ESS in EV charging. Key inputs in the study included new battery costs, charging station demand, battery repurposing cost, battery state of health and battery degradation characteristics (Lieskoski et al., 2024; Tarar et al., 2023).

In this research, secondary data on motor vehicle registration in Kenya between 2018 and 2023 was obtained from Kenya National Bureau of Statistics (KNBS) (KNBS 2024 Economic Survey, 2024). This data was used in the development of a predictive model of electric motor vehicle registration trends in Kenya for a 15-year period. The predictive model was developed through investigation of the historical vehicle registration trends and market analysis trends, which suggest that the motor vehicle industry in Kenya is growing at a rate of 9.1% as of year 2019 (Kanja, 2023). Data analysis was implemented through Microsoft excel to develop projections on the future trends of EV adoption in Kenya through trend line analyses and graphical representation. The economic evaluation of the various scenarios was simulated in Microsoft excel spreadsheets using the criteria of NPV, benefit to cost ratio, payback period and LCOS. The results were presented through graphical and tabulated formats.

The technical evaluation involved analysis of EV charging demand and analysis of availability of expired EV batteries for purposes of reuse in secondary applications. In the economic assessment, a detailed cost analysis covering the initial capital investment, operational expenses, and long-term profitability of second life battery use was determined. It considered potential revenue from reconditioned batteries, outlining break-even points and return on investment under various market conditions by utilizing different battery states of health and under incentivization conditions when reviewing pricing scenarios. Further investigations into similar research provided semi-empirical data, which has been used in sections of the economic evaluation of data.

3.4 Data Collection

Data collection is a critical phase, and relevant data must be available to inform the analysis. The data collection process in this context involved multiple streams of information, including technical specifications, economic figures, market trends, policy frameworks, and stakeholder inputs.

Technical data consisting of specifications of EV battery capacity, degradation characteristics and lifecycle; processes for repurposing, along with associated efficiencies and throughputs were reviewed (Haram et al., 2021). Economic data including repurposing cost of second life batteries; information on market prices for second life batteries; capital and operating expenditure for setting up and running an EV charging station and estimates of potential revenue from charging stations using these batteries was obtained through semi-empirical data (Lieskoski et al., 2024) and incorporated into the economic evaluation.

Market and industry forecasts include growth projections for the EV market; current and future supply of second life batteries anticipated in the market; dynamics of demand for second-life battery applications; best practices and innovative models in battery second life management globally (Hossain et al., 2019) were assessed.

The specific methods of data collection included literature reviews and analysis of existing databases. Based on the scope and resources of the study, secondary data sources that included KNBS vehicle registration data (KNBS 2024 Economic Survey, 2024) and semi- empirical data from literature review were used to fill the knowledge gaps and validate model assumptions. The amount of data available for this study was adequate to deduce research findings and draw useful conclusions. As the data set consisted of motor vehicle registration information over a period of six years it did necessitate clean up. The data cleanup was implanted within the excel platform by extracting the EV data from the entire dataset.

3.5 Model Development

Model development is a systematic process that combines various data sets and assumptions to create a simulation or representation of the real-world scenarios. The objective is to analyze and compare the technical variables, costs of repurposing EV batteries for storage applications in EV charging support for off-grid charging stations and determine return on investment in this setup.

3.5.1 Material Flow Analysis

This study explores the economic viability of repurposing EV batteries for use in off-grid charging stations in the scenario of Kenya. Redeployment of EV batteries economically depends on the volume of EVs and available batteries for repurposing.

The MFA also considers EV lifespan. Richa et al., (2014) looked into EVs with a 10-year lifespan and a 15-year sensitivity study. This result comes from European light-duty vehicle research. This study will examine 15-year EV lifespans, like by (Pagliaro & Meneguzzo, 2019; Richa et al., 2014). This will allow examination of how different EV lifespans might affect the flow of EV batteries.

Figure 3.1 shows a material flow analysis (MFA) (Lieskoski et al., 2024)that captures material flow and stock in a physical system with space and temporal constraints. Consideration of battery and EV lifespans will predict the volume of EV batteries available for repurposing in 15 years using the 6-year motor vehicle data. A battery-repurposing company may choose a certain EV model due to the many manufacturers, models, and chemistries, though Kenyan EVB statistics favors lithium-ion batteries.

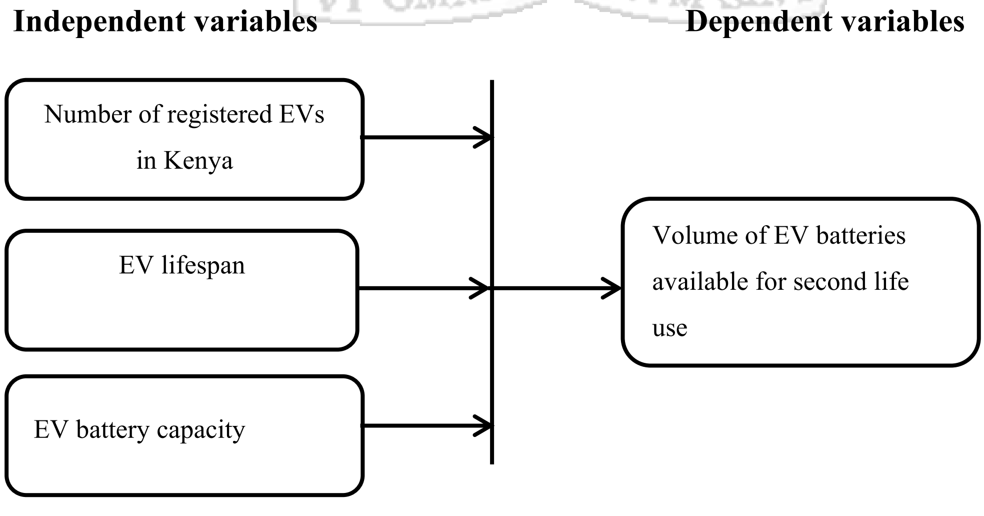


Figure 3. 1: Variables for Material flow analysis

Based on historical data, the prediction for EV deployment in Kenya assumed that the ratio of EVs to passenger cars and motorbikes continues to grow linearly (Kanja, 2023). Reportlinker research data estimates that total new motorcycle sales in Kenya have grown at a compound annual growth rate (CAGR) of 6.5% annually during the past five years (2019-2023). The market is expected to reach \$1000.2 million by 2028, increasing at a (CAGR) of 3.39% (Forecast: Motorcycles Market Size Value in Kenya 2024 to 2028, n.d.). On the other hand, Kenyan new motor vehicle registrations have fluctuated but declined over the past decade, with a decline of 4.65% in 2023 after a 9.4% increase in 2021. The five-year CAGR of -4.68% is anticipated by 2028. (Forecast: New Vehicles Registrations in Kenya 2024- 2028, 2025).

The compound annual growth rate (CAGR) is a metric used to determine the average annual growth rate of a value during a specified duration, presuming consistent annual growth. It is utilized to assess the average rate of return or growth over a time period. Equation 3.1 is used to determine the future value at a time n given the present value and CAGR are known.

$$FV = PV*(1+CAGR)^{n} \qquad \text{Equation 3. 1}$$

FV = future value
PV = present value
CAGR = compound annual growth rate
n = time period

This estimated deployment of the motor vehicles and motorcycles was used to evaluate the future EV share of total EVs in Kenya by 2038. Although EV battery lifespan uncertainties require further research, this MFA model assumed a moderate, fixed EV lifespan of 8 years. Therefore, in the year 2038 it is estimated that all EVs registered before 2030 will have attained their EOL in EV use and should be available for repurposing.

Assuming each EV is powered by one battery and the recovery rate of batteries after disassembly from EVs is 75%, the number of available EV batteries for repurpose will therefore be computed from the governing Equation 3.2. This approach has been taken from a similar MFA in a research by (Lieskoski et al., 2024).

$$\text{Volume of EV batteries} = N*E_{Battery}*\eta_{Recovery} \qquad \text{Equation 3. 2}$$

N =Number of retired EVs
$C_{Battery}$ = Battery energy (kWh)

$\eta_{Recovery}$ = Battery pack recovery efficiency

3.5.2 Second Life Battery Cost and Incentivization Model

For decommissioned EV batteries, the primary treatment strategies are repurposing, recycling, and disposal. The optimal approach is to initially reuse the batteries, followed by recycling or appropriately disposing of the batteries based on the evaluation score (Haram et al., 2021). When repurposing a substantial quantity of decommissioned batteries, it is imperative to address technical obstacles such as safety concerns, assessment methodologies, sorting and reassembling processes, and effective management strategies (Hua et al., 2021). Obtaining a complete historical dataset, accurately identifying second life applications, and finding the optimum position between accuracy and processing cost are the primary technical hurdles that need to be overcome.

Battery manufacturers have investigated avenues for value generation via battery repurposing, yielding additional revenue while also decreasing the expenses associated with new batteries. Currents, (2024), McKinsey & Company reported that second life batteries for electric vehicles could provide cost reductions of 30 to 70% compared to new batteries. Figure 3.2 illustrates the expenses associated with a repurposed battery in comparison to a new battery.

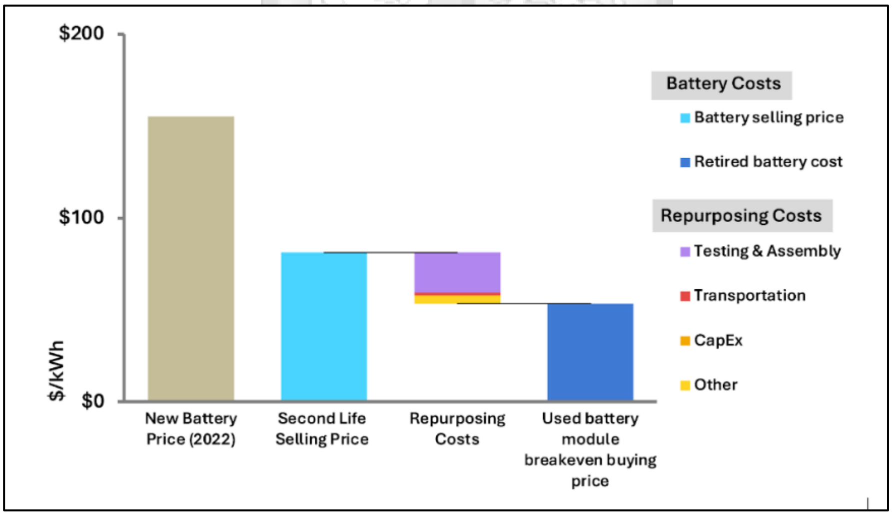


Figure 3. 2: Cost of a repurposed battery against a new battery source: (Currents, 2024)

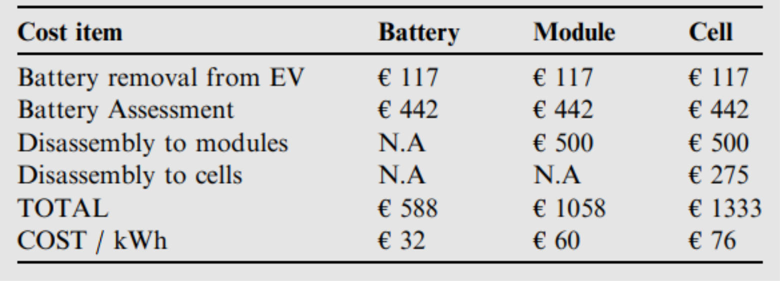
This research emphasized on Lithium ion batteries, which have been widely adopted for use in EV in comparison to other available battery chemistries (Macharia et al., 2023). The SLB purchase price was economically assessed by considering all battery re-purposing expenditures, including testing, assembling, transportation, and others. The selling price was calculated by adding the purchase price, repurposing costs, and a targeted profit margin. SLB's price included battery replacement. SLB should always offer a cheaper choice for customers, even when battery prices decrease. Haram et al., (2021), stated that the SLB formula's price should reflect the battery's revised cost. The battery's SOH and repurposing cost must also be considered. The discount element was added to encourage suppliers and electric car users to use SLB. Thus, the purchase price is presented through Equation 3.3

$$P_{used} = P_{new} * f_{SOH}(1 - f_{reuse} - f_{discount}) \qquad \text{Equation 3. 3}$$

P_{used}: SLB price in the nth year.
P_{new}: New batteries of similar capacity price in nth year.
f_{SOH}: Battery SOH (%)
f_{reuse}: Re-purposing cost of SLB (%)
$f_{discount}$: The discount factor (%)

To encourage use of second life batteries, a discount factor was introduced to the second life battery pricing model in Equation 3.3. In this study the discount factor is equated to an investment tax credit incentive for buyers of second life EV batteries for secondary application (Comello & Reichelstein, 2016). A similar model is adopted in the economic evaluation in this dissertation. An assumption is made that all the costs involved in the re-purposing such as testing, assembling, transportation and others are considered under P_{used} as defined in Table 3.2. A similar cost analysis for repurposing EV batteries from an extensive experimental investigation by Rallo et al., (2020). Using a 17.6-kWh Smart for Four EV battery, this was used to calculate the costs of disassembling electric vehicle batteries at each step. The duration and staff resources needed at each stage were documented and converted into expenses. The cost research showed the cost per kWh for the entire battery pack (without deconstruction), modules, and cells. In this study the re-purposing cost factor is assumed to be 15% as presented in the study by (Rallo, Benveniste, et al., 2020).

Table 3. 2: Cost analysis of repurposing EV batteries (Haram et al., 2021; Rallo, Benveniste, et al., 2020)



Cost item	Battery	Module	Cell
Battery removal from EV	€ 117	€ 117	€ 117
Battery Assessment	€ 442	€ 442	€ 442
Disassembly to modules	N.A	€ 500	€ 500
Disassembly to cells	N.A	N.A	€ 275
TOTAL	€ 588	€ 1058	€ 1333
COST / kWh	€ 32	€ 60	€ 76

The transfer of batteries after they were taken from the electric vehicle (EV) was not included in the cost, suggesting it was done at the same evaluation location. Repackaging, BMS, and wiring costs were also ignored. According to SLB literature, repurposing and selling costs might range from optimistic to fair to high. Canals Casals et al. (2019) examined the economics of using SLB in residential settings and found that buying SLB at €38.3/kWh is profitable.

Batteries constitute 30% to 40% of the overall expense associated with a new electric vehicle, thereby influencing the elevated purchase price of EVs (Currents, 2024). A Bloomberg report indicates a decrease in battery prices, with the average cost of a battery electric vehicle pack at USD 128 per kWh in 2023 (Stoikou, 2023). Statista a global data and business intelligence platform has presented similar data on the volume weighted average lithium-ion battery price indicating that prices declined steadily between 2010 and 2020 reaching 137 USD per kWh (Roper, 2020). The price of a LIB is normalized using the purchasing power parity normalization ratios in USD and normalizing to its KES cost equivalent using Equation 3.4

$$\text{Normalized price (KES)} = \text{Foreign Price (USD)} * \frac{\text{PPP Conversion factor (KES)}}{\text{PPP Conversion factor (USD)}} * \text{Exchange rate } (\frac{\text{USD}}{\text{KES}})$$

Equation 3. 4

The Levelized Cost of Storage (LCOS) quantifies the average present cost of electricity discharged, incorporating all expenses associated with the installation, charging, and discharging of an energy storage system over its operational lifespan. The Levelized Cost of Storage (LCOS) determines the average cost per kilowatt-hour (kWh) of electricity released from a storage system throughout its operational lifespan. This calculation incorporates all associated expenses, including capital expenditures (CAPEX), operational expenditures (OPEX), charging costs, and applies a time discounting factor (Schmidt et al., 2019). The LCOS was determined using Equation 3.2, with the following assumptions

i. The lithium ion battery will degrade at a rate of 4.7% per annum based on the cycle count (Harper, 2025).
ii. The depth of discharge is calculated at 85%.
iii. The number of charging and discharging cycles was one per day.
iv. Round trip efficiency (RTE) was computed as energy delivered versus energy used to charge the battery, expressed as a percentage.
v. The discount rate was assumed to be 14%. This is in line with the current average bank lending rates in Kenya ("Bank Lending Rates in Kenya 2025," 2025).
vi. The estimated lifespan of the second life battery was 4 years.

$$LCOS = \frac{Capex + \sum_{n=1}^{N} {(Opex + C_{Charge})}/{(1+r)^n}}{\sum_{n=1}^{N} {(C_{Cycles} * DoD\ (\%) * Cap_{Nom} * RTE\ (\%))}/{(1+r)^n}} \qquad \text{Equation 3. 5}$$

Capex = Capital expenditure in purchasing battery ($US)

Opex = Operating expenditure ($US)

C_{Cycles} = Battery cycles in a year

C_{Charge} = Cost of charging a battery per year ($US)

Cap_{Nom} = Nominal battery capacity (kWh)

DoD = Depth of Discharge (%)

r = Discount rate (%)

n = Battery life in years

RTE = Round trip efficiency (%)

The net present value was used to determine cash flow projections for the charging station business. Equation 3.3 presents the net present value (NPV) discounted over time, t

$$NPV_{Cost} = \sum_{t=0}^{T} \frac{Ct+Mt}{(1+r)^t} \qquad \text{Equation 3. 6}$$

C_t = Capital cost in year t

M_t = Operation and maintenance cost in year t

r = Discount rate

t = Assumed lifetime of the project

$$NPV_{Revenue} = \sum_{t=0}^{T} \frac{Bt}{(1+r)^t} \qquad \text{Equation 3. 7}$$

B_t = Project revenue in year t

r = Discount rate

t = Assumed lifetime of the project

3.6 The Charging Station

3.6.1 Introduction

This model is based on an off-grid solar photovoltaic plant integrated with battery storage. A maximum power point tracking (MPPT) charge controller will manage the charging and discharging cycles of the BESS and monitor the number of connected EVs through system loading. A monitoring system was installed to monitor the time of arrival of EVs to determine the amount of time required to charge each EV. The PV plant was mounted on a carport structure at the parking lot of the implementing facility. Based on the space requirements, the panels were installed on an available rooftop following outright purchase or a lease to own business model.

3.6.2 Charging Demand

An EV charging demand assessment is necessary for EV charging infrastructure planning. This is vital in setting targets for the number of public EV chargers as well as location planning and strategic siting of EV charging stations for ease of accessibility and optimal utilization of available infrastructure. This will be useful from an investment perspective as well owing to the input capital cost per station.

Kenya's EV demand was estimated using the motor vehicle registration data obtained for this study. The electric motorcycle was used as a case study to design the charging stations following the current growth pattern and registration trends between 2018 and 2023. The data shows a growing trend in number of registered EVs in Kenya with highest growth rates recorded in motorcycles as seen in Table 3.3

Table 3. 3: Number of registered electric motor vehicles in Kenya by year (KNBS 2024 Economic Survey, 2024)

SN	BODY TYPE	2018	2019	2020	2021	2022	2023	TOTAL
1	BUS/COACH	0	0	0	0	3	18	**21**
2	FORKLIFT	8	13	24	40	22	33	**140**
3	MOTORCYCLE	44	96	28	144	366	2,557	**3,235**
4	S.WAGON	11	15	30	57	33	41	**187**
5	SALOON	0	0	1	1	2	4	**8**
6	THREE-WHEELER	0	4	21	35	40	39	**139**
7	OTHERS	2	1	2	7	9	2	**23**
	TOTAL	**65**	**129**	**106**	**284**	**475**	**2,694**	**3,753**

The EV charging demand can therefore be obtained by multiplying the number of registered EVs by the battery energy per EV. This is presented in Equation

$$\text{EV Charging Demand} = N * E_{\text{Battery}} \qquad \text{Equation 3. 8}$$

N = Number of registered EVs

E_{Battery} = Nominal energy for EV battery

The average battery capacity is estimated to be 3.24 kWh (48V). These registration trends have necessitated a need to increase the charging infrastructure at a similar rate to match the available EVs. The registered EVs in Kenya are graphically represented in Figure 3.2

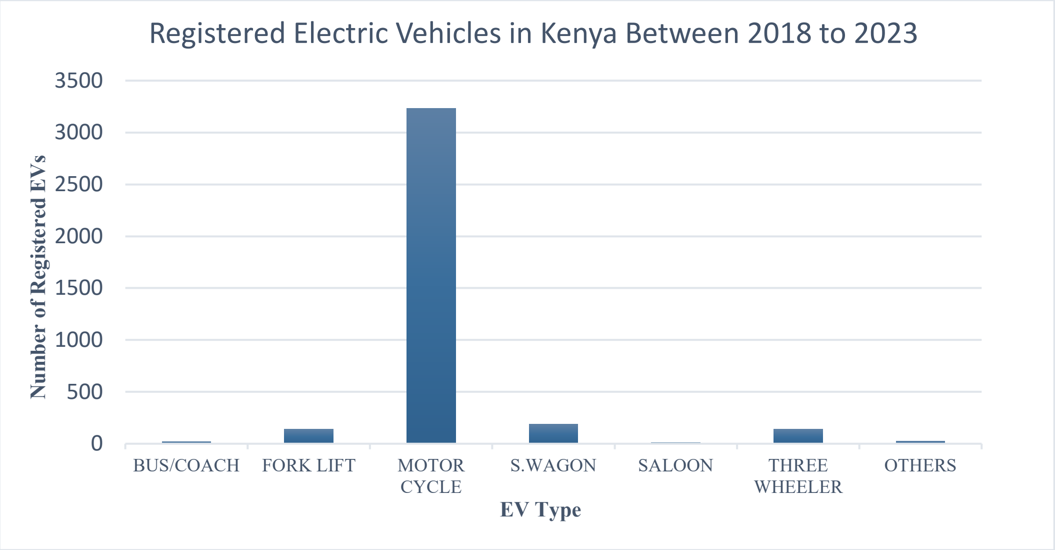


Figure 3. 3: Number of registered EVs in Kenya Source KNBS Data

3.6.3 Load Profile for EV Station

The load profile was determined from motor vehicle registration data (KNBS 2024 Economic Survey, 2024). The registered motorcycles, which possess an average battery capacity of 3.24 kWh and an estimated range of 70 km per full charge. The motorcycles can accommodate one or two similar batteries simultaneously: facilitating extended range and enabling the use of one battery while the other charges. This research examines daytime charging of electric vehicles (EVs) during sunlight hours and utilizing surplus charge available during idle periods to charge the BESS to full capacity. Among the 3,235 registered e-motorcycles, each necessitating 4 hours for full battery charging, 41,925.6 kWh of energy would be required for charging. Charging is decentralized across multiple locations, leading to an estimate that a single EV charging station can accommodate approximately 20 EVs per day. For the charging station, the consumption profile is considered constant with a total load of 64.8 kWh per day.

3.6.4 Solar PV System

Kenya receives daily solar insolation of 4-5kWh/m^2 across most regions, with an average of 5-7 peak sunshine hours per day (Marcel et al., 2020). The solar PV plant design considered factors such as the number of EVs to be charged, SOC of available BESS, number of sunshine hours and average solar irradiance of the selected area. Ambient conditions such as the temperature also affect the temperature of the solar cells, and therefore the design reference temperature will be set at 25°C, with average ambient temperatures in Kenya ranging between 11.0 – 31.1°C (Marcel et al., 2020) an average of 21°C is used in the sizing. Number of PV panels N is given by the equation 3.5 in (Jenkins & Ekanayake, 2024).

$$N = \frac{Load\ demand\ (kWH)}{P * ASH * \eta * [1-(Tc-25)0.5\%]} \qquad \text{Equation 3. 9}$$

$ASH = Avearge\ Sun\ Hour$

P = panel $rated\ power$

$Tc = cell\ temparature$

$\eta = overall\ rated\ efficiency$

For a 64.8kWh per day PV plant, assuming an average of 6 sunshine hours per day a 545W monocrystalline solar PV module with an efficiency of 21.6% defined by its manufacturer was selected for this design. From manual computations based on equation 4.1, with an ambient design temperature of 21°C, each charging station will require 90 solar PV panels to meet the daily demand. The array will consist of 6 parallel strings each with 15 panels in series giving a total open circuit voltage of 624V.

The solar panel data is presented in Table 3.4

Table 3. 4: Solar PV Module data. Source (Davis & Shirtliff Product Manual, 2025)

Rated Power (W)	Nominal Voltage (V)	Peak Voltage (V)	Open Circuit Voltage (V)	Short Circuit Current (A)	Efficiency (η)
545	24	41.6	49.8	13.88	21.6%

3.6.5 Battery Energy Storage System (BESS)

Due to the variability of the solar power resource, a battery energy storage system is proposed to provide a stable power supply. Proposed number of batteries can be determined by the Equation 3.6 as in (Ali et al., 2019),

$$n = \frac{Energy\ demand * Days\ of\ autonomy}{Battery\ voltage * DoD * Battery\ Ah * Battery\ Efficiency} \qquad \text{Equation 3. 10}$$

n = Number of batteries required

DoD = Depth of discharge

For a second life battery, an assumption has been made that the battery efficiency is 75% of its original state.

A 210kWh (608V, 346AH) has been proposed, with an efficiency of 75% assuming a state of health of 75% and 85% DoD to ensure longevity of the battery. The number of batteries required per charging station based on a 64.8kWh per day loading and 2 days of autonomy is calculated based on Equation 3.6 and determined that 1 battery will be installed to charge 20 batteries. Table 3.5 presents the BESS characteristics.

Table 3. 5: Battery Energy Storage Characteristics

Battery Capacity (AH)	Battery Voltage (V)	Battery Energy (kWh)	Battery SOH
346	608	210	75%

3.6.6 Charge controller

The MPPT charge controller provides a linkage between the PV generator and the DC load. The Charging will be operated in three modes as follows (Reddy & Kamesh, 2016), with the nomenclature outlines as below

P_G as power from PV plant

P_B as power from BESS

P_L as power demand

Mode I: $P_G > P_L$ and P_B is between maximum and minimum limits, the Power will be supplied to the EV and surplus power to BESS.

Mode II: $P_G > P_L$ and P_B is out of limits, the surplus power will be supplied to secondary loads for Power balance. These may include power to charge batteries in a battery swapping station.

Mode III: $P_G < P_L$ and P_B is in between limits, the demand from EV is supplied by ESS.

The charge controller size is obtained by the equation below (Cao, 2024)

$$c = \frac{Array\ size}{Battery\ voltage} * 25\%\ safety\ factor \qquad \text{Equation 3. 11}$$

From a computation using Equation 3.7, the maximum system current is determined as 100.8A, hence a total of 100A charge control system is proposed consisting of 1*100A, selected to ensure temperature compensation, load control and efficiency.

3.6.7 EV Charging Station Architecture

Consists of the cabling, isolation mechanisms, metering and user data collection systems.

i. RFID (Radio Frequency Identification technology) facilitates the acquisition of the State of Charge (SOC) value from electric vehicle (EV) batteries, enables the assessment of the number of EVs in the charging process, and supports user billing.
ii. An LCD screen is utilized to display the charging status, availability of charging slots, and the number of electric vehicles charged.
iii. Relays ensure the safety of equipment and facilitate the connection and disconnection of electric vehicles (EVs), battery energy storage systems (BESS), and photovoltaic (PV) plants at the station.

3.7 Choice of Simulation Software

The selection of simulation software was a pivotal decision that profoundly influences the study's results. The chosen program was proficient in managing intricate studies, assimilating varied data sets, and offering comprehensive modeling functionalities for both technical processes and economic assessments. A variety of modelling softwares were evaluated for this research. HOMER Pro was assessed for its appropriateness in optimizing microgrids while assessing the viability of recycling electric vehicle batteries for energy storage solutions. GAMS was assessed for its application in optimization and economic analysis, especially in systems requiring the evaluation of numerous interdependent decisions. These software applications were considered inappropriate for this research because their proprietary nature restricts user-developers' capacity to modify and enhance the product. R Studio provides a multifaceted platform with extensive uses, including modeling battery degradation, economic studies, and facilitating custom model building; MATLAB Simulink was evaluated for this research. The later softwares proved too technical to study and incorporate in this research due to the short period the research was done. After careful consideration of available modelling tools, Microsoft excel was determined to be the most appropriate for this research because of its variety, user-friendliness, and ability to facilitate the creation of tables and figures required for presentation of results in this study.

3.8 Evaluation of Results

The results highlight the distinctions in economic viability between repurposing and the use of new batteries. Potential business models for engaging in the second life battery economy for specific applications as EV charging station energy storage system are discussed, and recommendations made for applicable business models.

Key parameters investigated in the study were,

i. Material availability
ii. Cost per kWh of SLB repurposing
iii. EV charging station infrastructure development
iv. Levelized cost of storage and net present value of using the repurposed EV batteries.

The results have been evaluated through graphical representation using Microsoft excel. In addition, trend lines have been used to show the projection of EV trends and cost estimations over time. The Levelized cost of storage and net present value have been implemented in the economic evaluation of the viability of the venture within the projected battery life.

3.9 Ethical Consideration

This research follows the highest ethical standards to protect participants and research integrity. The following ethical concerns were made during research methodology and study execution. The study was conducted using secondary data on motor vehicle registration between 2018 and 2023, obtained from the Kenya National Bureau of Statistics (KNBS). NACOSTI principles and other relevant guidelines and legislation to protect participants' dignity and rights were followed. The Strathmore University Ethics Committee approved the research proposal for ethical compliance.

The research presents substantial benefits that have been assessed to surpass any associated risks to individual participants or society. No experimental processes or data collection involving participant interaction occurred during the research; therefore, there was no necessity to maintain information integrity or protect confidentiality through informed consent. The research was conducted ethically and responsibly aiming to enhance the existing body of knowledge, safeguarding the welfare and rights of participants while maintaining the integrity of the data by using it in its original form.

3.10 Conclusion

This chapter has discussed the methodology employed in the research highlighting the research design, data management strategies and sources and model development. This section further discusses how the results were evaluated and the ethical considerations in this research. The model under material flow analysis looks at the motor vehicle registration data and how the vehicles age over time to eventually yield retired batteries. The economic evaluation criteria of LCOS, NPV, B/C ratio and break-even analysis are used to estimate the second life battery price that would be profitable. The LCOS is also used for prediction of cash flow within the BESS lifespan.

Chapter 4: Results & Discussion

4.1 Introduction

This chapter brings the findings from the research, answers the research questions, and provides feedback on how the research objectives have been met.

4.2 Analysis of Results

From a review of the secondary data obtained from KNBS, there is a linear increase in the number of EVs registered in Kenya. There is, however, an exponential increase in the number of 2-wheeler motorcycles in the Kenyan context observed from the year 2023. Figure 5.1 presents a graphical representation of the total number of registered EV by model in Kenya Between 2018 and 2023.

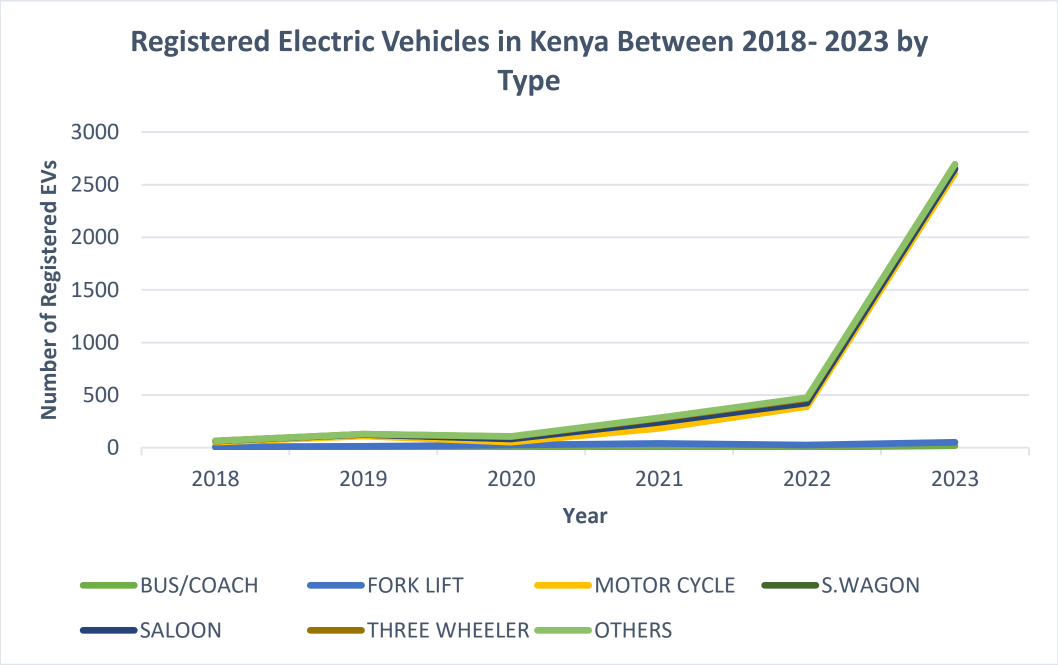


Figure 4. 1: A graphical presentation of the total number of registered electric vehicles in Kenya between 2018 and 2023 from KNBS data

Data obtained on vehicle registration trends between 2018 and 2023, from KNBS was used to obtain projections of the number of EVs anticipated to be registered in Kenya in the next 15 years (2038) as represented in Table 4.1.

Table 4. 1: Projection of the number of registered EVs up to 2038

BODY TYPE	**1 (2018)**	**2 (2019)**	**3 (2020)**	**4 (2021)**	**5 (2022)**	**6 (2023)**	**Total Projected registered number of EVs by 2038 (15 years)**
BUS/COACH	0	0	0	0	3	18	**209**
FORKLIFT	8	13	24	40	22	33	**793**
MOTORCYCLE	44	96	28	144	366	2557	**52,540**
S.WAGON	11	15	30	57	33	41	**615**
SALOON	0	0	1	1	2	4	**87**
THREE-WHEELER	0	4	21	35	40	39	**911**
OTHERS	2	1	2	7	9	2	**44**
TOTAL	**65**	**129**	**106**	**284**	**475**	**2,694**	**55,199**

Further, projections were carried out on the volume of batteries that would be available for secondary use in the coming 8 years, assuming an EV battery lifespan of 8 years as shown in Figure 4.2. The CAGR projected for the Kenyan automotive sector growth rate was used to obtain these results

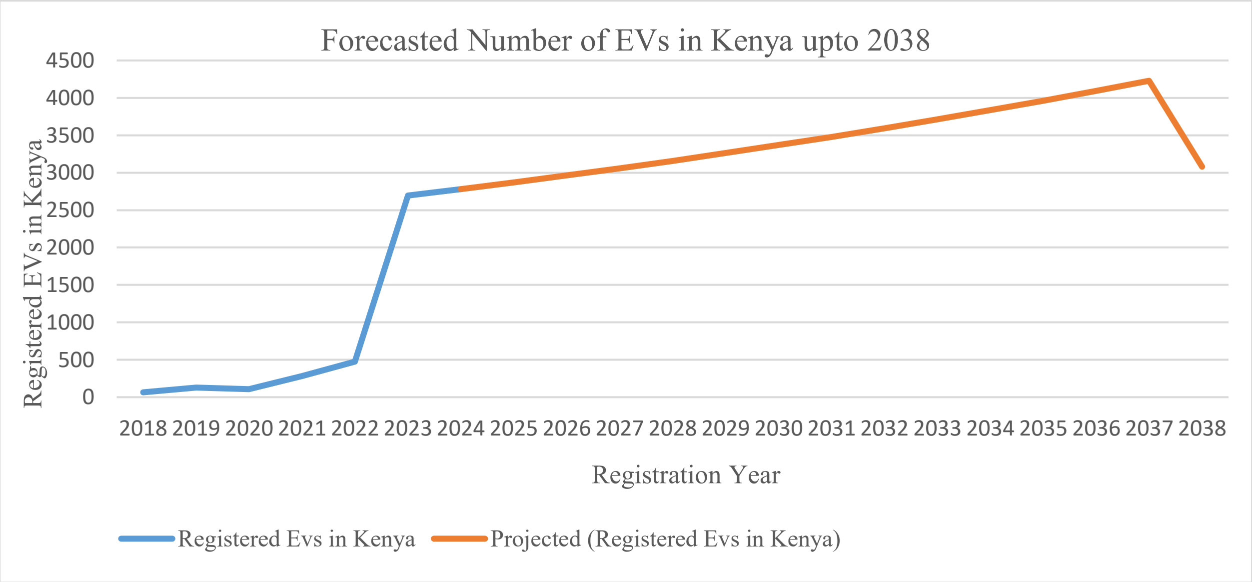


Figure 4. 2: A graphical representation of the number of EVs projected to be registered in Kenya in the next 15 years

It is anticipated that the number of registered EVs will continue to rise following a linear trend for all EVs. However, the motorcycles and three-wheeler EVs will increase at a higher rate due to the CAGR predictions. The trends are likely to be as a result of a number of 2-wheeler motorcycle OEMs setting up assembly facilities in Kenya such as ROAM, ebee, ewaka, tryke, little app Kenya, Kiri EV and Arc Ride (Deal, 2023). Other operators in the ecosystem include EV chaja who are charging point operators and ampersand, who provide battery-swapping services and have established battery-swapping stations that serve the needs of these motorcycle users with ease of accessibility and affordability of the service. The 2-wheeler motorcycles are also relatively more affordable than their ICE equivalents when a comparison of acquisition and operational and maintenance costs are made. The 2-wheeler numbers have largely been embraced by commercial delivery businesses, such as Uber Electric, which have adopted the EVs for improved operational efficiency in addition to sustainability and these companies focus on their net-zero goals (Nzomo, 2024).

The station wagon's increasing trend can be attributed to the inflow of electric vehicles for the uber business with short travel distances around the cities, which are more economical than their ICE equivalents. In addition, the setting up of various EV OEM dealerships in Nairobi such as BYD and NETA means that these manufacturers are accessible by the consumers for operation and maintenance services, building local trust in their brands. In addition, various players in the vehicle supply chain have started to import used EVs to Kenya at more affordable cost such as UTU cars operating within East Africa (*UTU Africa*, 2025).

The linear increase in the adoption of coaches, buses, and saloon cars can be attributed to affordability as a significant factor. High initial capital investment requirements and substantial passenger capacity per unit limit the frequency of new acquisitions. Additionally, concerns regarding range anxiety and battery capacity for buses, trucks, and lorries, which are primarily utilized for long-distance travel and heavy-duty applications, are exacerbated by the lack of a well-developed charging infrastructure network in off-grid locations.

The EV charging demand in the next 15 years is based on growth projections as determined by equation 3.7 which shows that a total of 55,199 EVs will have been registered by 2038. However, as aged EV batteries are removed from existing EVs, it is anticipated that new batteries retaining the number of EVs in operation will replace these. Table 4.2 shows the total EV charging demand for EVs in circulation in Kenya by 2038. This projection assumes that any EVs whose batteries have been disused were replaced following the EV not having been retired from use.

Table 4. 2: Projected charging demand based on the number of registered EVs by 2038

EV TYPE	Total Projected registered number of EVs by 2038	Average battery size (kWh)	Total projected EV charging demand by 2038 (kWh)
BUS/COACH	209	210	43,885.48
FORKLIFT	793	11	8,723
MOTORCYCLE	52,540	3.24	170,230
S.WAGON	615	40	24,607
SALOON	87	87	7,582
THREE-WHEELER	911	11	10,018
OTHERS	44	102	4,476
TOTAL	**55,199**		**269,523**

By 2038, it is estimated that electric vehicles registered between 2018 and 2030 will have attained a state of health (SOH) of 75% to 80% after at least eight years of operation, taking into account various factors influencing EV battery aging. These batteries will be utilized in second life applications via repurposing or recycling. Table 4.3 presents an estimate of the quantity of second-life electric vehicle batteries anticipated for second-life applications by 2030.

Table 4. 3: Estimated number of retired EV batteries that will be available for second life application by 2030

Type of EV	EVs Projected to reach EOL in 8 years (2030)	Average battery size (kWh)	Total Estimated EOL EVB by 2030 (kWh)
BUS/COACH	94	210	19,766
FORKLIFT	303	11	3,337
MOTORCYCLE	17,800	3.24	57,671
S.WAGON	319	40	12,751
SALOON	30	87	2,614
THREE-WHEELER	339	11	3,726
OTHERS	26	102	2,648
TOTAL	**18,911**		**102,512**

The design of an off-grid PV charging station in section 3.6 proposed a 64.8kWh per day load profile, which can provide charging support for approximately 20 motorcycles with a battery capacity of 3.24kWh when charging directly from the battery for 4 hours, hence 7,280 EVs charged per year. This gives a repurposed battery a utilization efficiency of 20%.

This dissertation found that a 64.8kWh per day PV charging station with a 210kWh BESS could charge 1,456 EVs with 3.24kWh batteries for 4 hours. This yields 25% battery efficiency. In a similar research, Singh et al., (2021) built an optimization model for a solar-powered electric vehicle charging station and found that an 8.1kWp system with two days of battery autonomy has the lowest unused energy losses and a decent performance ratio. The researchers also found that this system could charge 414 vehicles of battery capacity 30kWh annually. Additionally, the researchers found that towns around the equator produced the most energy from January to March. Their charging station assumed a daily usage profile of 2.5 kW per hour, or 60 kWh per day. In their EV charging station setup, the PV array generated the energy from dawn to evening during sun hours. The residual energy charged the battery bank after meeting the energy demand. The charge controller restricted instantaneous energy generation to consumer energy needs and battery capacity. The battery banks powered EVs overnight and early morning.

4.3 Economic Evaluation

In this analysis, Equation 3.3 was used to determine the cost of a repurposed EV battery. The cost of a new large-format lithium ion battery pack used in an EV is estimated to be USD 139/kWh (Roper, 2020). This price is normalized using the World Bank PPP conversion factor of KES 43.29 per USD (*PPP Conversion Factor, GDP (UCL per International $)*, 2023), to cost KES. 6,017.31 (46.56 USD per kWh, exchange rate KES 129.24 per USD). Research by (Rallo, Benveniste, et al., 2020) suggested that EV battery repurposing cost would be €32/kWh which is normalized using PPP conversion factor of € 0.69 against 1USD (*PPP Conversion Factor, GDP (UCL per International $)*, 2023). Therefore, the estimated cost is 46.40 USD per kWh.

The cost of a repurposed battery pack was computed between 80% and 50% SOH and the discount factor between 0%, 15% and 30% using Microsoft excel analysis. Table 4.4 shows the average cost of a repurposed EV battery pack. The SLB price decreases as the discount is applied making the pack more affordable. To encourage the purchase of these second-life batteries, it is therefore necessary to price them with a suitable discount.

Table 4. 4: Price of Second Life EV Battery Pack

	P (new) (USD)	f (SOH)	f (reuse)	f (discount)	P (used) (USD)
Scenario 1	46.56	80% - 50%	15%	30%	$16.65
Scenario 2	46.56	80% - 50%	15%	15%	$21.18
Scenario 3	46.56	80% - 50%	15%	0%	$25.72

4.3.1 Incentivization Model

An incentive is proposed for modeling the price of second life BESS. Similar to the investment tax credit applications, the incentivization model was employed to assess the cost of a repurposed battery, incorporating a discount factor relative to the purchase cost of a new battery for the second-life battery. The inputs to the cost of the dismantled battery include the cost of a new battery, a factor of the battery SOH, a factor of the repurposing cost and a discount factor that constitutes the incentive to the purchase cost. This research has factored discount factors between 0% in the most pessimistic scenario and 30% in the most optimistic scenario to determine the optimized incentivization factor for the repurposed battery cost. Optimization was achieved through obtaining the lowest LCOS which when used for revenue projections resulted in a break-even point early in the BESS project lifespan with subsequent profitability. The average cost of the BESS is presented in Table 4.4. The Figure 4.3 further illustrates the cost of a reused battery pack per unit considering SOH between 50% and 80% and a discount factor between 0% and 30%.

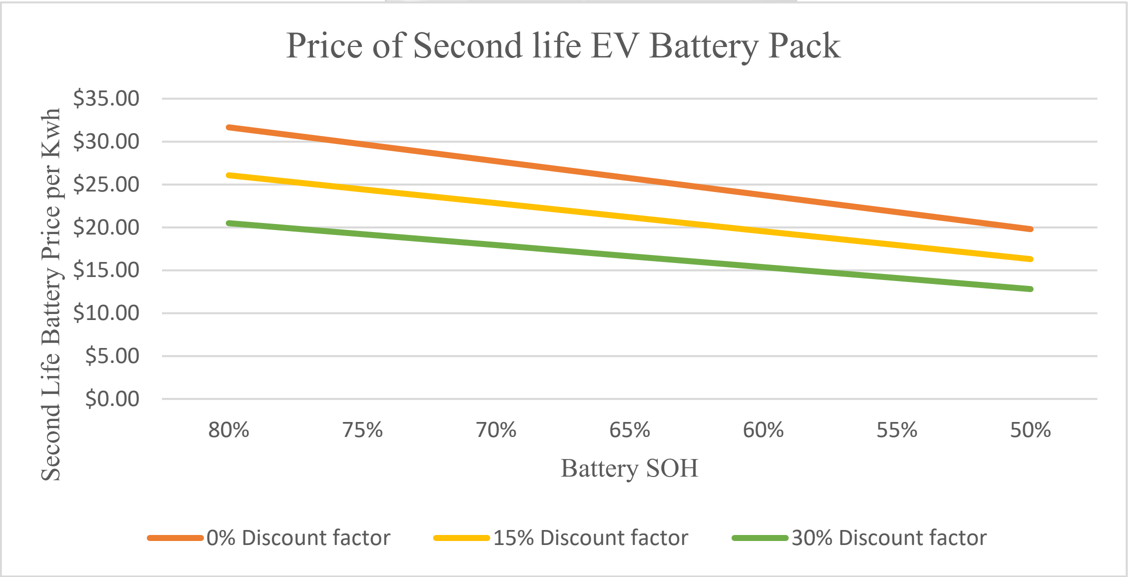


Figure 4. 3: Graphical representation of battery cost using the incentivization model

4.3.2 Levelized Cost of Storage (LCOS)

The LCOS was calculated as a ratio of discounted costs against the discounted energy supplied by the ESS throughout the lifetime of the ESS. Equation 3.5 was used to compute the NPV ESS with varying purchase cost over the project lifetime. The energy throughput was computed for a four-year battery lifespan at a discount rate of 15% and a battery degradation rate of 4.7% per annum is considered. Results of the LCOS as a factor of the battery price are presented in Table

4.5. The LCOS is used as an indicator of the charging cost per kWh to determine the cash flow projections and determine the break-even point of the venture.

Table 4. 5: The LCOS for SLB Purchased with discounts between 0% and 30%

	P (used) (USD)	f (discount)	LCOS (USD)
Scenario 1	\$16.65	30%	\$0.04
Scenario 2	\$21.18	15%	\$0.04
Scenario 3	\$25.72	0%	\$0.05

The values of LCOS in all the three scenarios show that the EV charging stations become cheaper than the current electrically charged EVs that are charged either individually in households or through battery swapping stations. The LCOS values of US\$ 0.03 and US\$ 0.05 are lower in comparison to the cost of charging per day through a battery swapping station, which is charged at \$0.15 per day for the 2-wheeler roam motorcycle battery swapping stations and direct charging cost per battery of \$0.23/kWh (*Roam*, 2023). It is therefore more cost effective to use the off-grid EV charging stations proposed.

4.3.3 Net Present Value

The Net present Value (NPV), which is defined as the present discounted value of revenue over the lifetime of the BESS, was determined using Equation 3.7. Three different Scenarios have been presented with revenue forecasts within a four-year battery lifespan.

Table 4. 6: Revenue forecast scenarios with different average SLB prices

Revenue forecast Scenarios	**Price of a second use battery (USD)**	**NPV over 4-year battery lifespan**	**Break-even point**
Scenario 1	\$16.65	395	Year 4
Scenario 2	\$21.18	(564)	Beyond ESS lifespan
Scenario 3	\$25.72	(1,517)	Beyond ESS lifespan

The revenue projections are determined under three price scenarios using the repurposed battery prices in table 4.5 and the LCOS is taken as the indicative cost of charging an EV per kWh. Under Scenario 1, the NPV over the 4-year battery lifespan is determined as 395 USD with a break-even point on the fourth year. For the second and third scenarios where the BESS has a 0% and 15% incentive, the systems do not attain their break- even points during the BESS lifespan. This therefore means that the charging station would need to price the charging cost to the customers at a higher value than the computed LCOS in order to recover their investment cost and make their venture profitable. Figure 4.4 represents the NPV of the BESS over the anticipated 4- year lifespan.

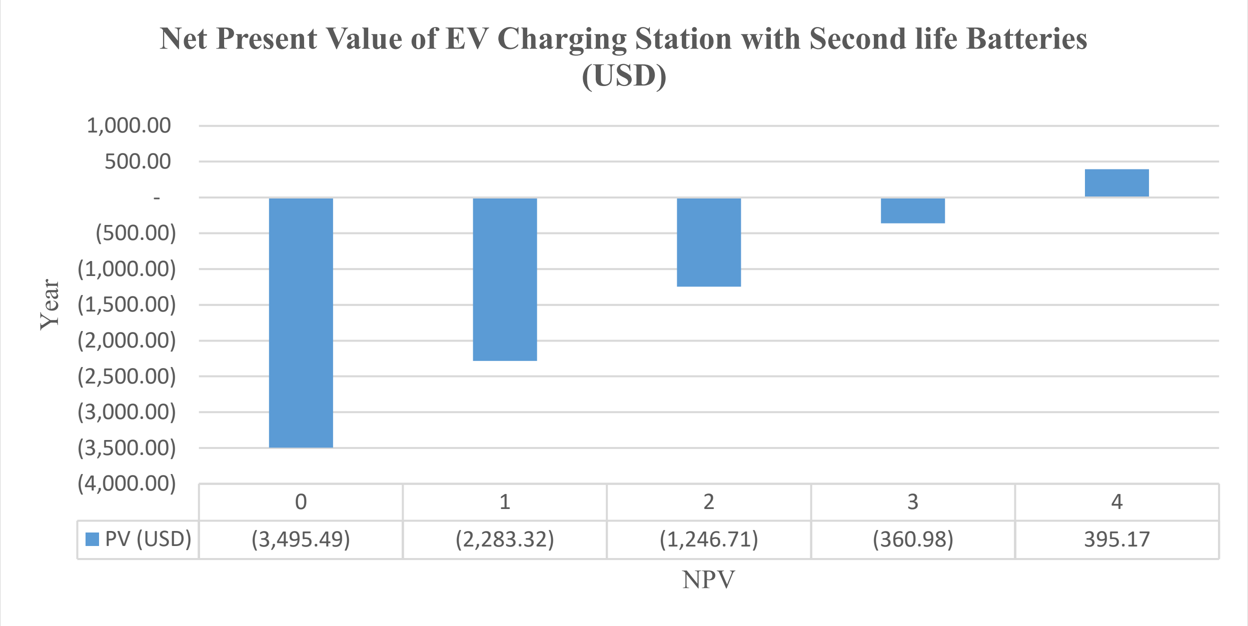


Figure 4. 4: Net present value of repurposed BESS for Scenario 1

4.3.4 Cost to Benefit Analysis of a Second Life Battery to a New Battery in the EV Charging Station

A cost benefit analysis was conducted on two scenarios with similar infrastructure where a second life battery was used in scenario 1 and a new battery was used in scenario 2. The cost estimates are presented in Table 4.7. The computational data was obtained from various price catalogues, following

Table 4. 7: Cost comparison between an investment in a new battery and a second life battery in an EV charging station

		Scenario 1 (Charging Station with SLB)	**Scenario 2 (Charging Station with New Battery)**
COMPONENT	**QUANTITY**	**TOTAL COST (USD)**	**TOTAL COST (USD)**
Solar Panels	90	7,021	7,021
Solar Panels mounting	49,050	8,729	8,729
Battery	210	3,517	9,778
Battery enclosure	346	134	134
Charge controller	1	623	623
Wiring and communication architecture	1	3,004	3,943
Civil works	1	831	896
Miscellaneous expenses	1	1,193	1,556
Labour expenses	1	1,803	2,566
TOTAL CAPITAL EXPENDITURE		**26,854**	**35,246**

From the computation, it is evident that the cost of a charging station utilizing a new battery would be much higher in comparison to the second life battery. However, the new battery has certain advantages over the second life battery in relation to ageing patterns such as degradation characteristics, and the general lifespan as calculated from the SOH perspective.

The NPV of the EV charging station is computed and it is observed that the EV charging station incorporating the repurposed battery will have a net present value of $ 2,243 in the 4th year, which is the last year of the projected battery lifespan. This therefore implies that either the cost of charging per kWh or volume will need to be optimized to ensure the venture's break-even point comes earlier in the projected BESS lifespan in order to have a better return on the investment. Figures 4.5 and 4.6 show the NPV over the lifetime of the batteries in this EV charging station. The assumption is that the other infrastructure in the charging station will exist beyond the ESS projected lifespan hence a re-investment would only occur in the case of BESS upgrade.

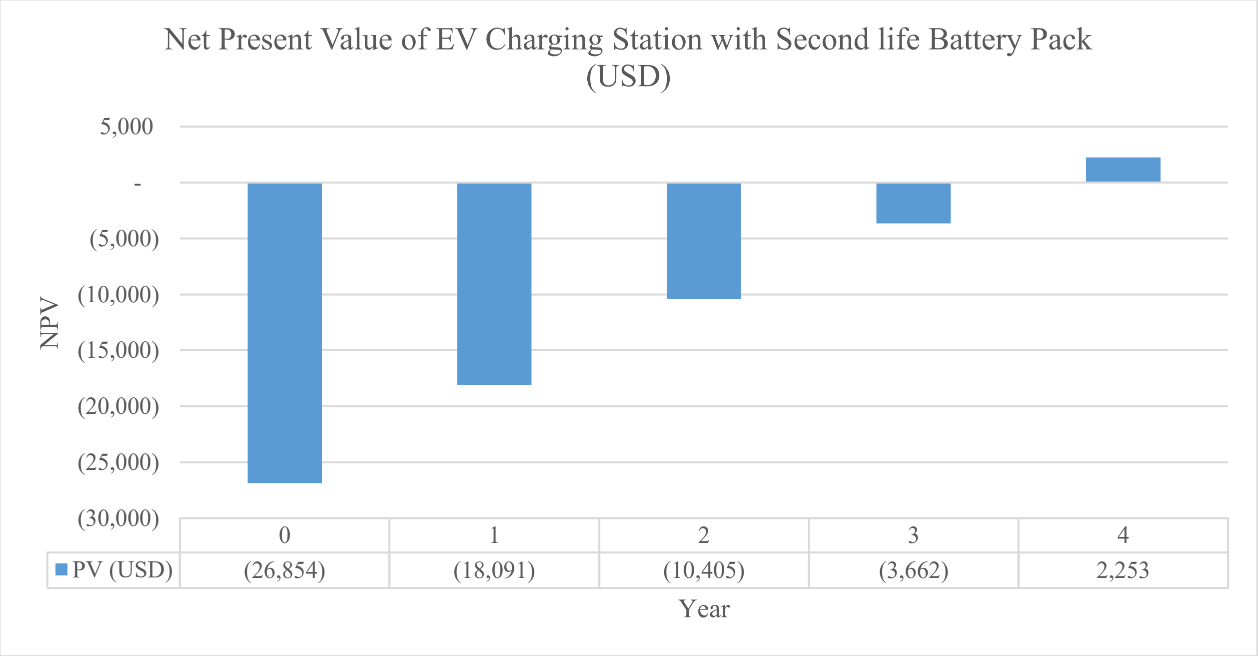


Figure 4. 5: Net present value of an EV charging station with second- life battery pack

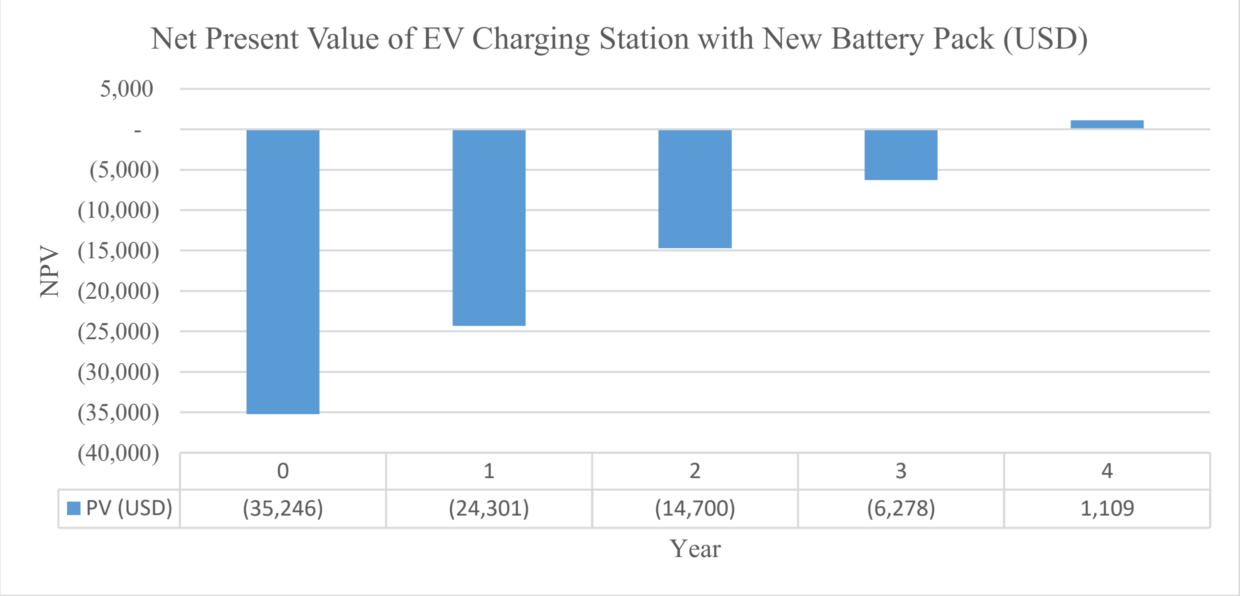


Figure 4. 6: Net present value of an EV charging station with new battery pack

The Given a higher investment cost, the NPV of an EV charging station using new batteries is still profitable with a break-even point on the fourth year. It is, however, anticipated that the charging cost per kWh will be much higher for the EV charging station with the new batteries at a minimum of $0.35 per kWh to enable it to become profitable.

For an EV charging station using a new battery pack, it is assumed that the ageing will follow a similar pattern as the new EV battery with a proposed degradation rate of 1.8% of maximum capacity per year (EV Connect, 2024). The LCOS is thus computed to be \$0.27 per kWh. The lifetime of the BESS is however anticipated to be longer and the NPV will have a better outlook since the breakeven point is on the 5th year with an NPV of \$ 4,651. The levelized cost of storage is, however, much higher and it is anticipated that the cost per unit of charge will likely be higher to cater for the initial capital investment.

Assuming a second life battery degrades at 4.7% each year, this research concluded that a second life battery in a charging station will last four years until it is no longer viable for BESS. Sandberg, (2023), found that a charging station BESS's second-life battery pack will reach the SOH lower threshold within four years, similar to this research. In addition, Al-Alawi et al., (2022), found that energy storage for energy arbitrage and frequency regulation could extend batteries' useful life beyond electric vehicle use and last more than 5,000 cycles under low current density.

4.4 Conclusion

The results chapter presented the findings of this research following observations and insights from the study. In the discussion, the research lists the limitations of the methodology through the assumptions and proposes further research into limitations of this work.

In the technical scope of this research, the material flow was investigated and found that though the EVs continued to be adopted at a faster rate globally, the passenger vehicles in Kenya would continue to be registered at a slower rate in comparison to the motorcycle EV. This therefore requires a further investigation into how to repurpose the lower capacity EV batteries for secondary applications that are less energy intensive and can accommodate the use of smaller battery packs.

The economic impact of repurposing EV batteries for use in off-grid charging stations was limited to the size and application of this study. As a result, the economic viability of this application may come into question due to the low NPV values in comparison to the initial capital investment estimates. It is therefore imperative to optimize the economic viability computations for this application to justify the return on investment over the predicted BESS lifespan.

Chapter 5: Conclusion and Recommendations

5.1 Introduction

This chapter presents a summary of how the research objectives and questions were addressed, key findings and takeaways. The section highlights the conclusion, adoption of results and recommendations for future work, stating who can benefit from the study and areas that remain to be further investigated.

5.2 Conclusion

This dissertation has investigated the technical and economic viability of repurposing second life EV batteries for use in energy storage in EV charging support. The study findings show that there will be a sufficient volume of retired EV batteries by 2030 to undertake various ESS second life applications including charging support in off-grid charging stations. The EV charging application is however quite energy intensive and it has been determined that as a result, the BESS will have a lifespan of 4 years in this application.

This research concluded that at a price of 16.65USD per kWh, the SLB would reach its break-even point in the fourth year. It is, however, not an ideal situation and therefore it is proposed that the charging cost per unit is increased to improve cash flow projections within the ESS expected lifespan. It is therefore desirable to charge the EVs at a cost above the estimated LCOS of $0.04 per kWh.

The benefit to cost ratio of using the SLB versus a new battery pack for the EV charging station ESS shows that the SLB being cheaper offers more value to the users for the reason that it will cost less to charge the EVs at an estimated cost of $0.28 per kWh than it would cost to charge the EVs using the new batteries with an anticipated charging cost of $0.35 per kWh. It therefore becomes 31% cheaper to invest in the SLB in an off-grid EV charging station than it would cost to use new batteries. Other than the environmental gains of not disposing of the retired batteries they are useful for a longer period.

This research proposes an incentive to the buying price of a SLB, which is commensurate with a discount of up to 30% to ensure the second life battery is more affordable compared to a new EV battery even as the global LIB costs continue to decline globally. The SLB price is recommended to be within the range of $16.65 and $21.18 per kWh to be repurposed profitably for the EV charging station application.

This research has made its contributions to knowledge through investigation of the EV battery waste in Kenya. The material flow analysis has given projections of availability of sufficient volumes of second life EV batteries for reuse. The findings show that at within a 15-year period, there will be 55,199 EVs on Kenyan roads, majority of which will consist of e-motorcycles. As the number of EVs rises, so will the charging demand and therefore the need to provide alternative EV charging mechanisms other than depending on the grid for EV charging needs. As a result, the available EOL batteries can be repurposed for use in EV charging stations for charging support.

Another contribution is on the second life EV battery pricing model investigated in this research. To enhance the cost efficiency of the retired EV batteries, the pricing should provide for mechanisms which allow for these batteries to be purchased at lower costs than the new EV batteries. By providing incentives such as investment tax credits to investors in the EV battery repurposing industry, the uptake of second life batteries is bound to increase. This will in turn promote circularity in the EV ecosystem as a result.

5.3 Adoption of Results

While this research was meant to investigate the technical aspects of designing an off-grid PV charging station with BESS support and utilized various assumptions based on empirical data from previous research, it has been observed that owing to the trends of EV registration in Kenya the charging infrastructure development should focus on the motorcycles and lower capacity EVs to optimize the use of renewable energy sources for EV charging and decrease reliance on the grid for EV charging. To address the variability of renewable energy sources such as solar, the second life batteries are considered for charging support as BESS in the off-grid PV station. Consequently, in economic viability it is proposed that the battery should be sold at a discount with discounting factors between 15% and 30% being recommended for optimal return on investment and payback periods within the project lifetime of four years before the batteries are fully degraded and due for replacement.

5.4 Recommendations for Future Work

This research studied repurposing of large format lithium-ion battery pack used in EVs, however, from the EV registration trends in Kenya, it is evident that the motorcycles, which are registered in large numbers, will become the next frontier for electric battery waste over the next decade. It is thus proposed that further research should focus on their management upon disuse in electric motorcycles that has not been a focus in this research.

With the technological advancements in EV battery chemistry and their functionality it is important for research to focus on the renewability and longevity of these EV batteries to promote the circularity of the e-mobility ecosystem, this results from the empirical data showing that the second life batteries are only useful for an additional four years in this application before they become subject to recycling or disposal. The remaining useful life was not a focus of this research due to limitation in scope, though has become useful in the analysis of viability of this proposed solution. The scope of this research did not consider proof of concept, which would be a favorable research direction for exploration.

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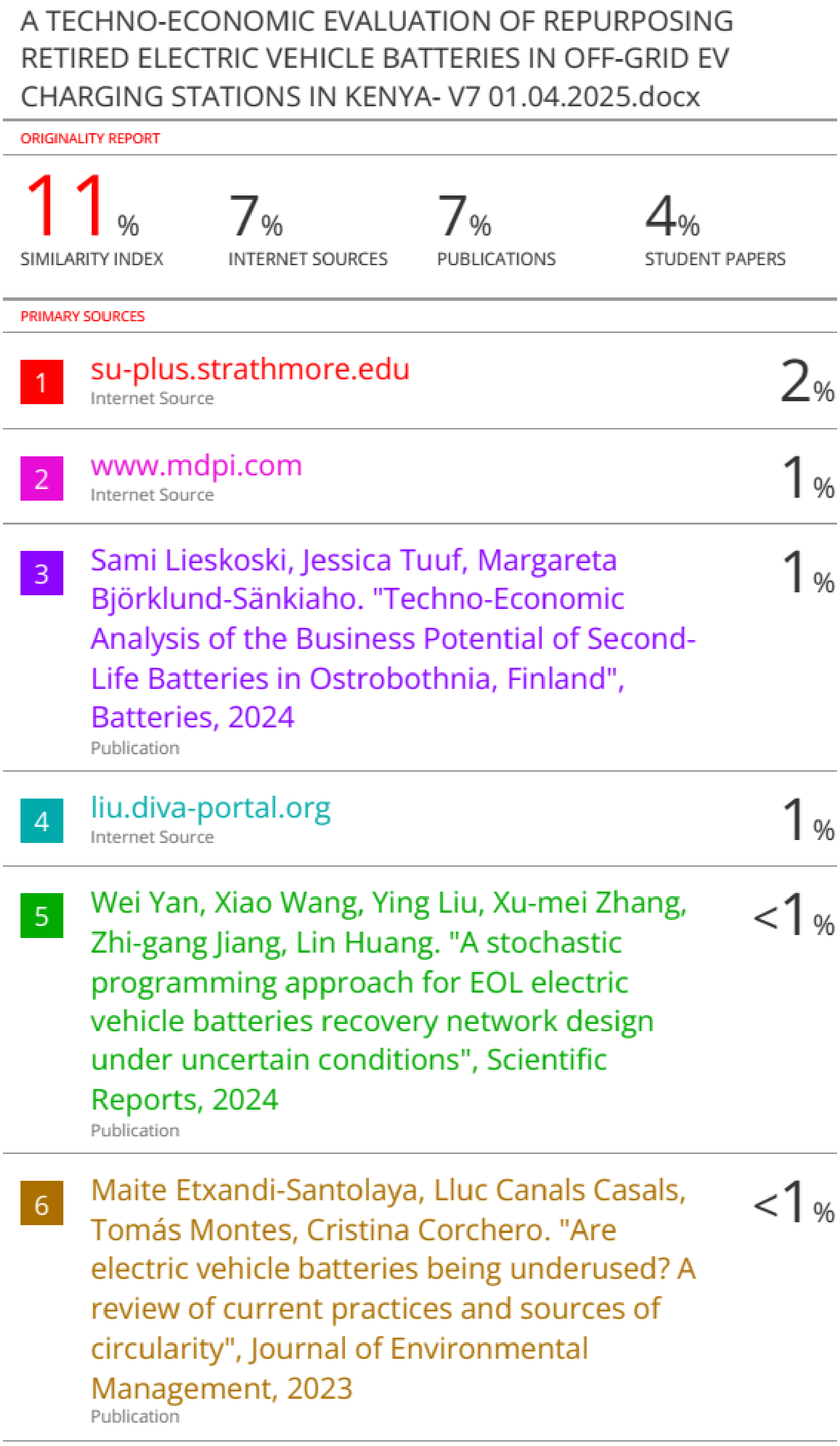
Appendices

Appendix A: Similarity Report



A TECHNO-ECONOMIC EVALUATION OF REPURPOSING RETIRED ELECTRIC VEHICLE BATTERIES IN OFF-GRID EV CHARGING STATIONS IN KENYA- V7 01.04.2025.docx

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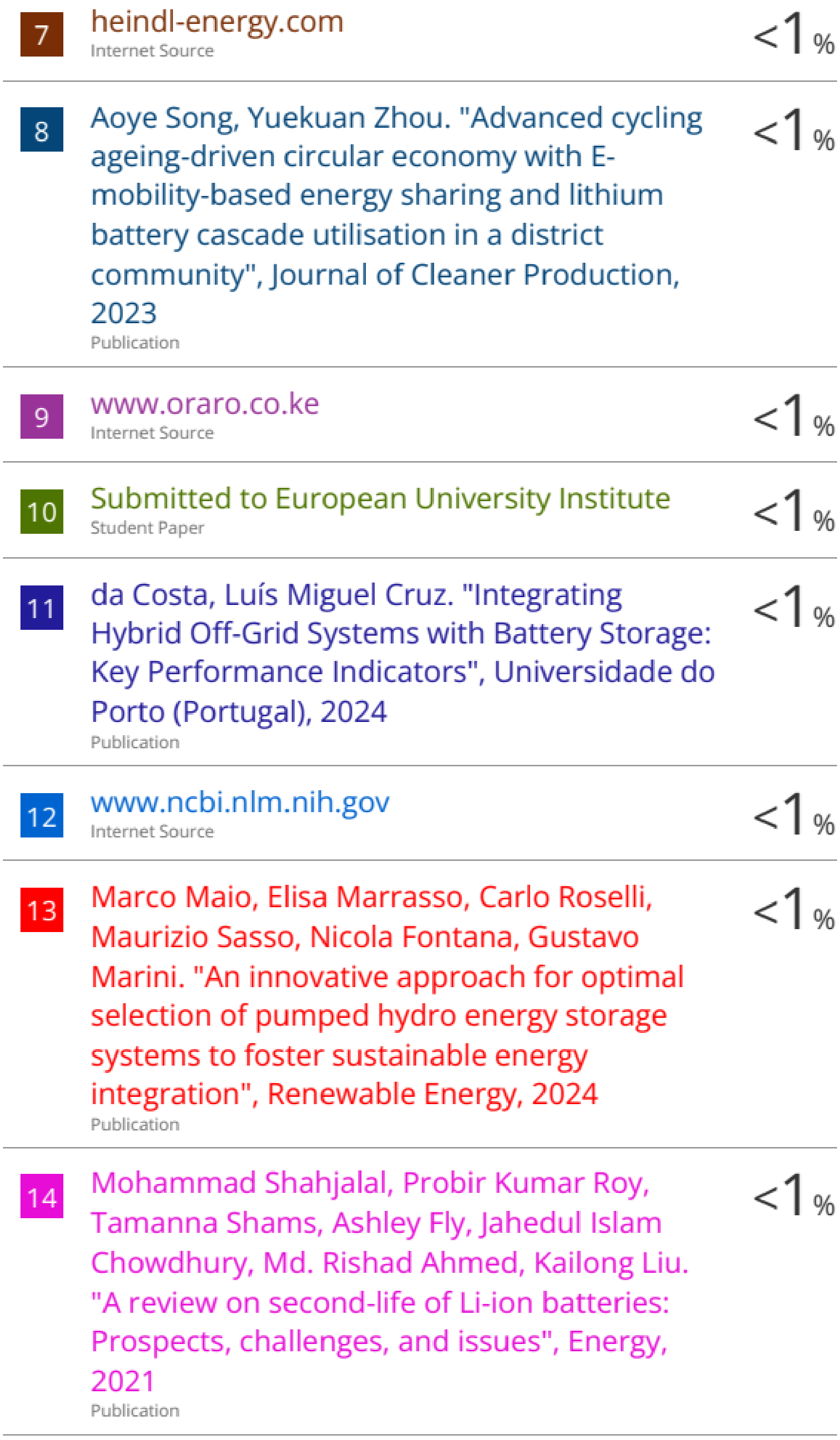

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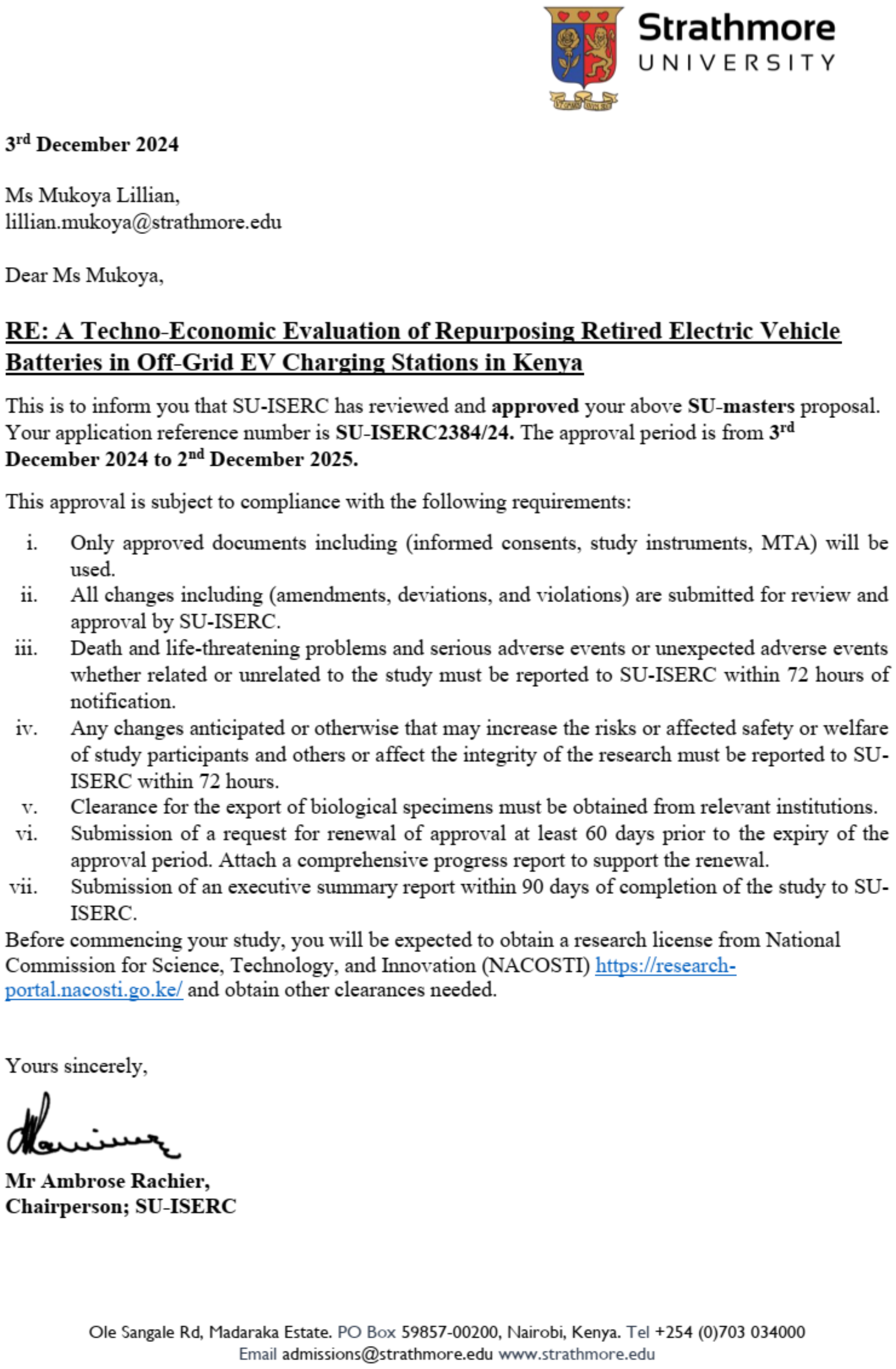
Appendix B: Ethical Clearance Confirmation



Strathmore
UNIVERSITY

3rd December 2024

Ms Mukoya Lillian,
lillian.mukoya@strathmore.edu

Dear Ms Mukoya,

RE: A Techno-Economic Evaluation of Repurposing Retired Electric Vehicle Batteries in Off-Grid EV Charging Stations in Kenya

This is to inform you that SU-ISERC has reviewed and **approved** your above **SU-masters** proposal. Your application reference number is **SU-ISERC2384/24.** The approval period is from **3rd December 2024 to 2nd December 2025.**

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-ISERC.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-ISERC within 72 hours of notification.
iv. Any changes anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-ISERC within 72 hours.
v. Clearance for the export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days of completion of the study to SU-ISERC.

Before commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology, and Innovation (NACOSTI) https://research-portal.nacosti.go.ke/ and obtain other clearances needed.

Yours sincerely,

Mr Ambrose Rachier,
Chairperson; SU-ISERC

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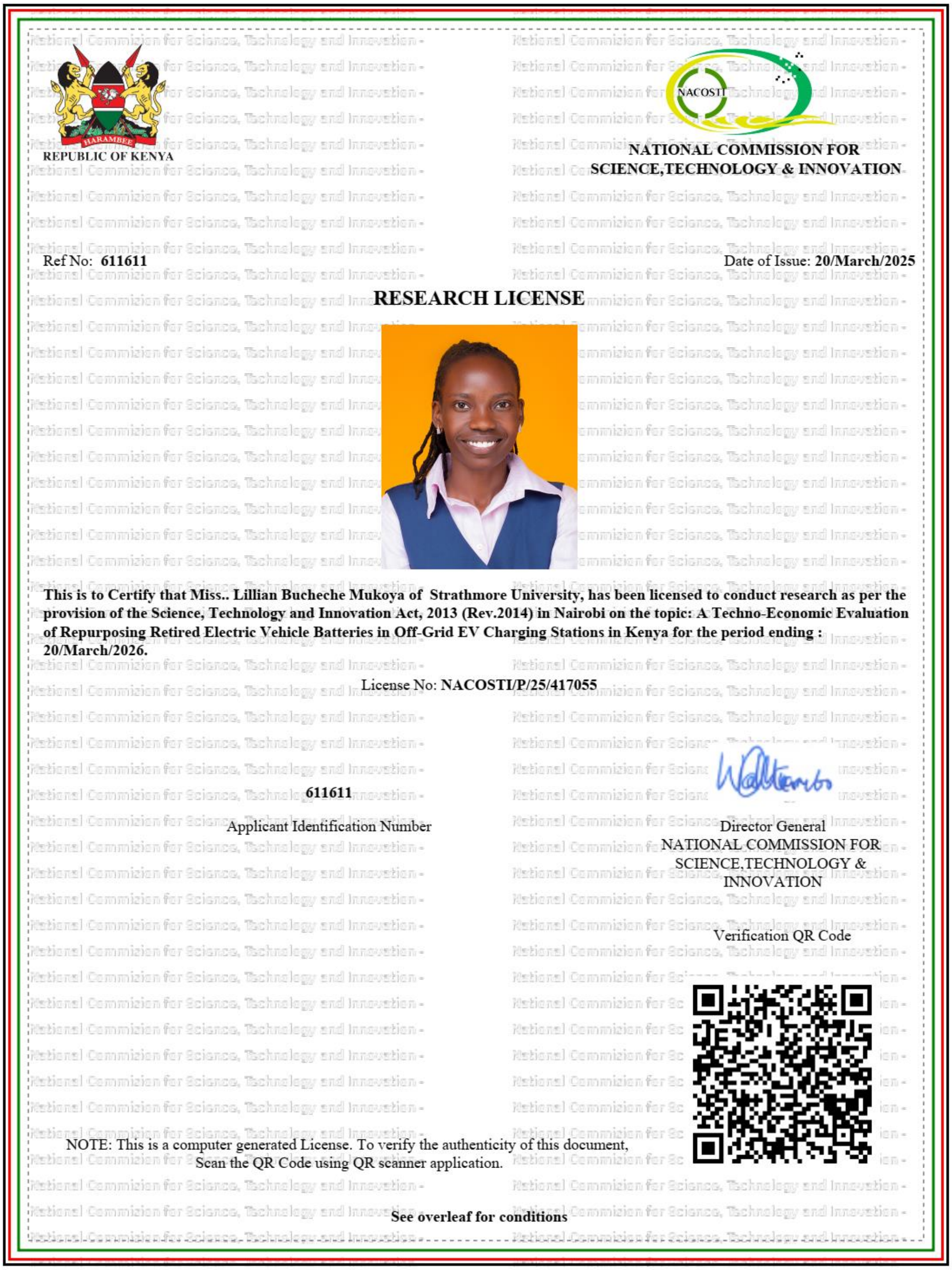

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