german
cooperation
DEUTSCHE ZUSAMMENARBEIT

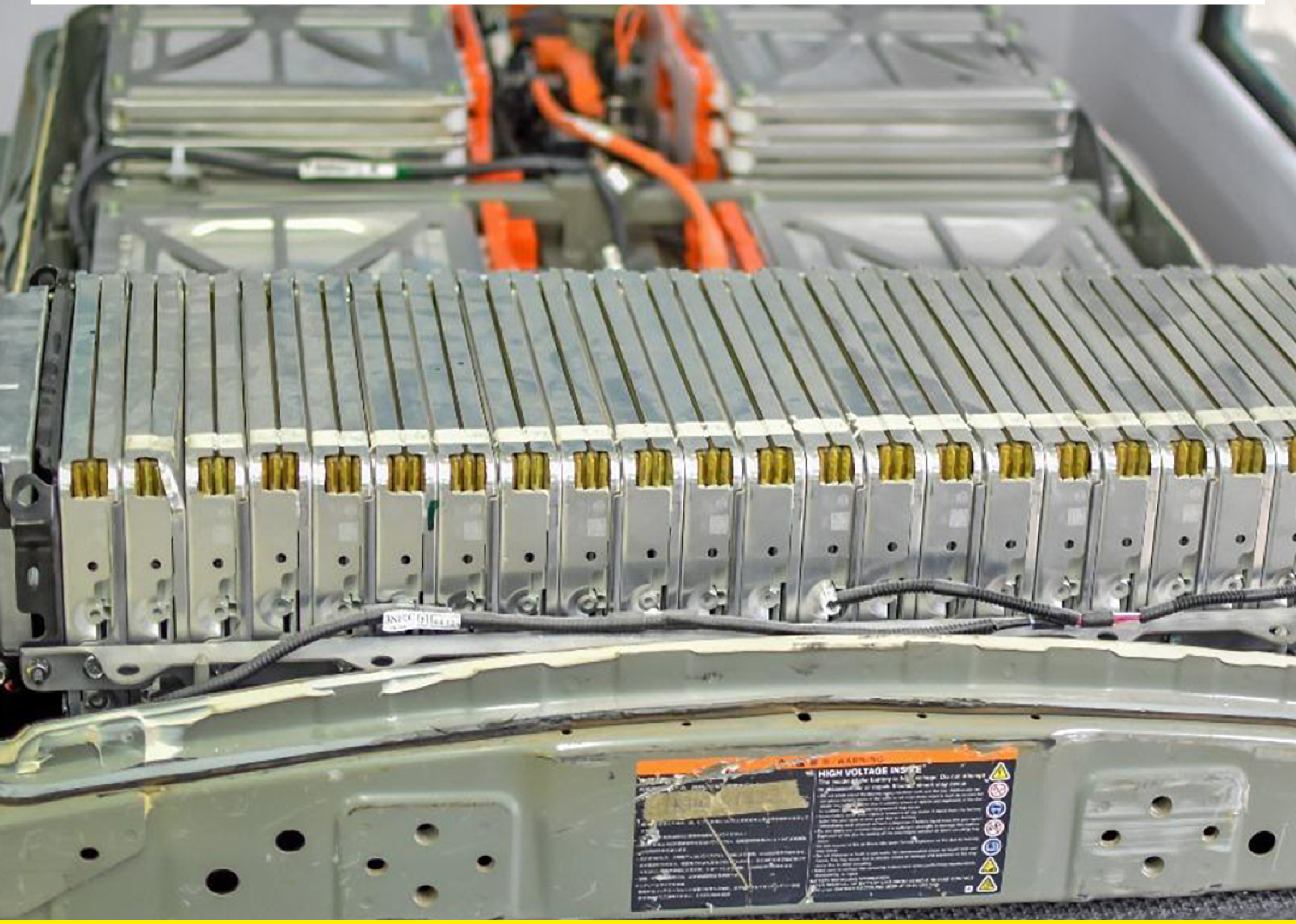
Co-funded by
the European Union

HARAMBEE

Implemented by

giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

KNIGHTS ENERGY
for professional Solar Solutions



Exploring Second-Life Applications of EV Batteries in Kenya

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Registered offices:
Bonn and Eschborn, Germany

Project:
This publication is part of the promotion of electric mobility in Kenya project funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and co-financed by the European Union and implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in cooperation with the State Department for Transport.

Address:
Energy, Transport and Climate Change Cluster
Promotion of Electric Mobility in Kenya.
P.O. Box 41607- 00100
Nairobi, Kenya

Disclaimer
While care has been taken in the collection, analysis, and compilation of the data, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH does not guarantee or warrant the accuracy, reliability, completeness, or currency of the information in this publication. The mention of specific companies or certain projects/products does not imply that they are endorsed or recommended by the members of this publication. The information provided is without warranty of any kind. GIZ and the authors accept no liability whatsoever to any third party for any loss or damage arising from any interpretation or use of the document or reliance on any views expressed herein. Responsibility for the content of external websites linked in this publication always lies with their respective publishers. GIZ expressly dissociates itself from such content.

Acknowledgements

This report is part of the "Techno-Economic Viability of Second-Life Applications for Electric Vehicle Batteries in Kenya" project. The report has been prepared by the Research and Development Extension of Knights Energy. Financed by the Federal Ministry of Economic Cooperation and Development (BMZ) and with great gratitude from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH for their role in implementing the project and providing invaluable guidance throughout.

Our appreciation also goes to Aceleron Africa, the Kenya Bureau of Standards, the National Environment Management Authority of Kenya, and the experts and stakeholders who generously shared their knowledge and insights, which were crucial to our understanding of Kenya's electric vehicle landscape and battery ecosystem.

Authours:

- Chandi Mosomi
- Abrahams Otieno
- Joy Makena

Technical Team:

- Bill Miranda
- Cyprian Sulwe

Advisors/Reviewers:

- Francis Romano
- Francis Njoka
- Herman Kwoba
- Jemimah Muli
- Robert Njoroge
- Michael Schuster

Designer/Contributors:

- Sandra Kirongothi

Contents

List of Tables

List of Abbreviations

ABM	Associated Battery Manufacturers
AfCFTA	African Continental Free Trade Area
AfEMA	Africa E-Mobility Alliance
Ah	Ampere-Hours
BaaS	Battery-as-a-Service
BESS	Battery Energy Storage System
BMS	Battery Management System
BMZ	Federal Ministry of Economic Cooperation and Development
BWMR	Battery Waste Management Rules
CACE	China Association of Communication Enterprises
CAPEX	Capital Expenditure
CAT	Centre for Alternative Technologies
CE	European conformity
CEC	China Electricity Council
CNESA	China Energy Storage Alliance
COP	Conference of the Parties
COVID	Corona Virus Disease
DRC	Democratic Republic of Congo
EA	East Africa
EMAK	Electricity Mobility Association of Kenya
EMCA	Environmental Management and Coordination Act
E-Mobility	Electric Mobility
EMS	Energy Management System
EOL	End-of-Life
EPA	Environmental Protection Act
EPR	Extended Producer Responsibility
ESG	Environmental, social, and governance
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
E-Waste	Electronic Waste
E-WIK	E-Waste Initiative Kenya
GBA	Global Battery Alliance
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatt
GWh	Gigawatt hour
HEV	Hybrid Electric Vehicle
HS	Health and Safety
HVAC	Heating, Ventilation and Air Conditioning
ICCT	International Council on Clean Transport

ICR	Lithium Cobalt Oxide Rechargeable
ICT	Information, Communication and Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IMR	Lithium Manganese Oxide Rechargeable
INR	Lithium Nickel Manganese Cobalt Oxide Rechargeable
IoT	Internet of Things
ISO	International Organisation for Standardisation
KEBS	Kenya Bureau of Standards
km	kilometre
KPLC	Kenya Power & Lighting Company
kW	kilowatt
kWh	kilowatt-hour
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LIB	Lithium-Ion Battery
Li-ion	Lithium Ion
LMO	Lithium Manganese Oxide
LMT	Light Means of Transport
LNMC	Lithium Nickel Manganese Oxide
LNO	Lithium Nickel Oxide
LTO	Lithium Titanium Oxide
MtCO2e	Megatons of Carbon Dioxide Equivalent
MWh	Megawatt hour
N/A	Not Applicable
NCA	Lithium Nickel Cobalt Aluminium Oxide
NDC	Nationally Determined Contributions
NEA	National Energy Administration
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organisation
NiMH	Nickel Metal Hydride
NMC	Lithium Nickel Manganese Cobalt Oxide
NTSA	National Transport and Safety Authority
OEM	Original Equipment Manufacturer
OPEX	Operational Costs
PPE	Personal Protective Equipment
QR Code	Quick Response Code
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
RUL	Remaining Useful Life
SMEs	Small and Medium Enterprises
SOC	State of Charge

SOH	State of Health
SyC SET	Systems Committee, Sustainable Electrified Transportation
TWh	Terawatt hour
UAE	United Arab Emirates
UIN	Unique Identification Number
UNEP	United Nations Environmental Programme
UPS	Uninterrupted Power Supply
US	United States
USA	United States of America
USD	United States Dollar
V	Volts
VAT	Value Added Tax
WEEE	Waste Electrical and Electronic Equipment

Executive summary

Kenya’s burgeoning electric vehicle (EV) market presents significant opportunities for second-life applications of traction batteries. This study aims to align with Kenya's low-carbon transport goals, focusing on the technical, commercial, and regulatory aspects of repurposing EV batteries. The specific objectives include:

- Documenting critical electro-technical parameters to evaluate EV battery reusability.
- Identifying cost-effective applications for repurposed EV batteries.
- Analysing the operations in both the formal and informal sectors of the battery reuse value chain.
- Assessing the longevity and economic benefits of second-life applications.
- Evaluating Kenya’s existing policy landscape and identifying implementation risks.

The global surge in EV adoption has intensified the focus on sustainable battery lifecycle management. In Kenya, as the EV market expands, there is an urgent need for effective strategies to handle used traction batteries. This project explores the potential for second-life applications of EV batteries, aiming to enhance economic value and minimize environmental impact. The study investigates practical uses, market potential, and necessary policy frameworks for sustainable integration into Kenya’s energy and transport sectors. The study delves into several key areas:

- Technical Viability: Comprehensive assessment of battery state of health (SoH), capacity fade, safety, and performance metrics.
- Economic Viability: Detailed cost analysis of repurposing batteries for diverse applications such as renewable energy storage, grid stability, EV charging stations, and backup power for critical infrastructure.
- Policy Framework: Examination of Kenya's e-waste regulations, including the EMCA 2015 and the Sustainable Waste Management Act of 2022, and recommendations for enhancing battery collection, national testing standards, safety regulations, and end-of-life management.
- Battery Management Systems: Evaluation of advanced battery management systems (BMS) and their role in ensuring safe handling, storage, and deployment of second-life batteries.
- Case Studies: Analysis of successful second-life battery projects in the USA, Japan, Europe, and Kenya, such as the Johan Cruyff Arena in Amsterdam and the Kikambala Parish School project.

A mixed-method approach was adopted, incorporating both quantitative and qualitative research techniques. Data collection entailed battery laboratory testing and interviews with stakeholders. Analytical tools included economic evaluations to assess market feasibility. The regulatory and policy analysis involved document reviews and consultations with agencies like the Kenya Bureau of Standards (KEBS) and the National Environment Management Authority (NEMA).

Diagnostic tools were used to measure battery parameters such as state of health (SoH) and capacity fade. Surveys and structured interviews captured market dynamics and stakeholder insights. Key participants included battery refurbishing companies like Aceleron Africa, regulatory bodies, environmental agencies, and informal sector representatives. Collaborative efforts provided a holistic understanding of the technical, economic, and regulatory environments.

Data analysis combined statistical methods for performance evaluation and economic modelling to assess feasibility. Qualitative insights from stakeholder interviews and policy reviews were thematically analysed, identifying barriers and opportunities, and leading to well-founded recommendations for regulatory improvements.

The study reveals promising technical and economic viability for second-life applications:

- Successful implementation of second-life battery applications, such as the Johan Cruyff Arena's 2.8 MWh battery energy storage system and the Kikambala Parish School's 7.7 kWh system piloted by Knights Energy, demonstrates the feasibility and positive impact on sustainable development.
- Various financial models, including outright purchase, pay-as-you-use (energy as a service), and lease-to-own, offer flexible acquisition options to meet diverse consumer needs.
- The cost of repurposing batteries varies based on application and market conditions, with estimates ranging from \$40 to \$160 per kWh. For example, Knights Energy's institutional battery pack priced at Ksh 185,000 (\$1600) for a 7.77 kWh system and residential battery pack at Ksh 65,900 (\$570) for a 2.4 kWh system.
- Second-life batteries are economically viable for applications such as renewable energy storage, residential energy systems, EV charging stations, and grid services, offering long-term cost savings and contributing to Kenya’s sustainable development.

The suitability of repurposed EV batteries for second-life applications in Kenya requires careful consideration of technical, commercial, and regulatory aspects. In the battery reuse value chain, the formal sector operates under structured regulations, ensuring safety, compliance, and environmental responsibility through standardized processes for battery collection, refurbishment, repurposing, and disposal. Conversely, the informal sector often focuses on cost-effectiveness and lacks regulation, which can compromise safety and environmental standards. While both sectors contribute economically, the formal sector emphasizes sustainability and quality, whereas the informal sector fosters innovation but may pose environmental and health risks due to improper handling and disposal practices.

Ensuring the safe handling, transportation, and disposal of second-life batteries necessitates comprehensive guidelines to mitigate risks such as thermal runaway, electrical short circuits, and chemical exposure. Key measures include transporting batteries at a reduced state of charge, conducting thorough inspections, using appropriate personal protective equipment (PPE), and maintaining controlled storage environments. Regular training, proper labelling, and adherence to emergency procedures are crucial, alongside strict compliance with regulations for disposal and recycling, to ensure safety and environmental responsibility throughout the battery's lifecycle.

Kenya's policy framework for e-waste, under which batteries are categorized, is shaped by several regulations, including the EMCA 2015 and the Sustainable Waste Management Act of 2022, which provides guidelines for extended producer responsibility (EPR). However, these regulations lack comprehensive guidelines on the second-life application of batteries. Recommendations include enhancing battery collection centres, expanding national testing standards, enforcing strict safety regulations, and improving end-of-life management for batteries. This aims to ensure the safe and efficient use of second-life batteries while protecting consumers and the environment.

Battery passports are also a critical component that can offer a framework for increased transparency and sustainability in the battery value chain. A Battery Passport serves as a comprehensive digital record that tracks the complete lifecycle of an individual battery, from the sourcing of raw materials to its refurbishment and recycling stages. It provides detailed information on the battery's composition, manufacturing process, performance metrics, and environmental impact. Implementing battery passports in Kenya can address challenges related to the expected growth of the importation of used electric vehicles and battery lifecycle management. While there are benefits such as improved sustainability, quality assurance, and data transparency, challenges include system standardization, data reliability, technical infrastructure, confidentiality concerns, and interoperability. To successfully implement battery passports in Kenya, the following recommendations need to be explored:

- Policy Development: Establishing national battery regulations aligned with global standards, promoting sustainability, and fostering stakeholder collaboration.
- Infrastructure Development: Creating a robust industry-wide digital system encompassing all actors in the value chain for data tracking, ease of interoperability, and addressing technical challenges.
- Policy Deployment: Encouraging manufacturer and stakeholder collaboration, integrating with other relevant policies, and developing implementation roadmaps.

In conclusion, by addressing these recommendations and learning from the EU's experience, Kenya can effectively implement second-life applications of EV batteries and battery passports to meet Africa's energy demands and contribute to a more sustainable and circular economy.

This comprehensive study not only outlines the feasibility of second-life applications for EV batteries in Kenya but also offers a pathway to sustainable economic and environmental outcomes, setting a framework for policy and regulatory enhancement.

1. Second-Life Battery Pack Applications

1.1 Case studies of successful second-life applications

The Johan Cruyff Arena in Amsterdam hosts a 3 MW solar PV and 2.8 MWh capacity energy storage system, the largest in Europe using second-life and new electric vehicle batteries.[1] This project, a collaboration between Eaton, Nissan, BAM, The Mobility House, and others, combines Eaton power conversion units and 148 Nissan Leaf batteries. It supports the Dutch energy grid by balancing supply and demand, providing backup power, and storing energy from the stadium's 4,200 solar panels.[2] This project has been operational since June 2018, and the storage has been upgraded to continue hosting 100% green events.

Similarly, the University of California, San Diego utilised second-life Mini-E batteries for renewable energy storage and fast charging, with a system capacity of 108 kW/180 kWh, enhancing the university’s energy infrastructure and research capabilities. The project includes four electric vehicle charging stations, a solar panel roof, and two second-life batteries. These second-life batteries, which have been repurposed from electric vehicles, help reduce the cost of the charging stations and make EV charging more affordable and sustainable. The University of California San Diego was recognised for this innovation (Margoni, 2016).

In Kenya, Knights Energy implemented a second-life battery project using a 2014 Nissan Leaf battery with a 7.77 kWh capacity at Kikambala Parish School (570 student capacity when fully enrolled) in Mombasa County. This system supports the school's solar energy setup, supplying power to essential loads like lights and ceiling fans, meeting a peak demand of 4 kW, and storing 7.77 kWh of energy at full capacity, which is utilised at night as demonstrated in the graph in Figure 2. Providing a consistent power supply for essential school operations, ensuring continuous power for learning activities. This project demonstrates the viability and benefits of second-life battery applications in educational institutions, and the inclusion of operations such as clean cooking and water pumping can be added to the system.

Figure 1The Setup of the 7.77 kWh Battery from a Nissan Leaf Battery

---

[1] David Pratt Ajax’s Amsterdam Arena

[2] Eaton Making the Johan Cruyff Arena more energy efficient.

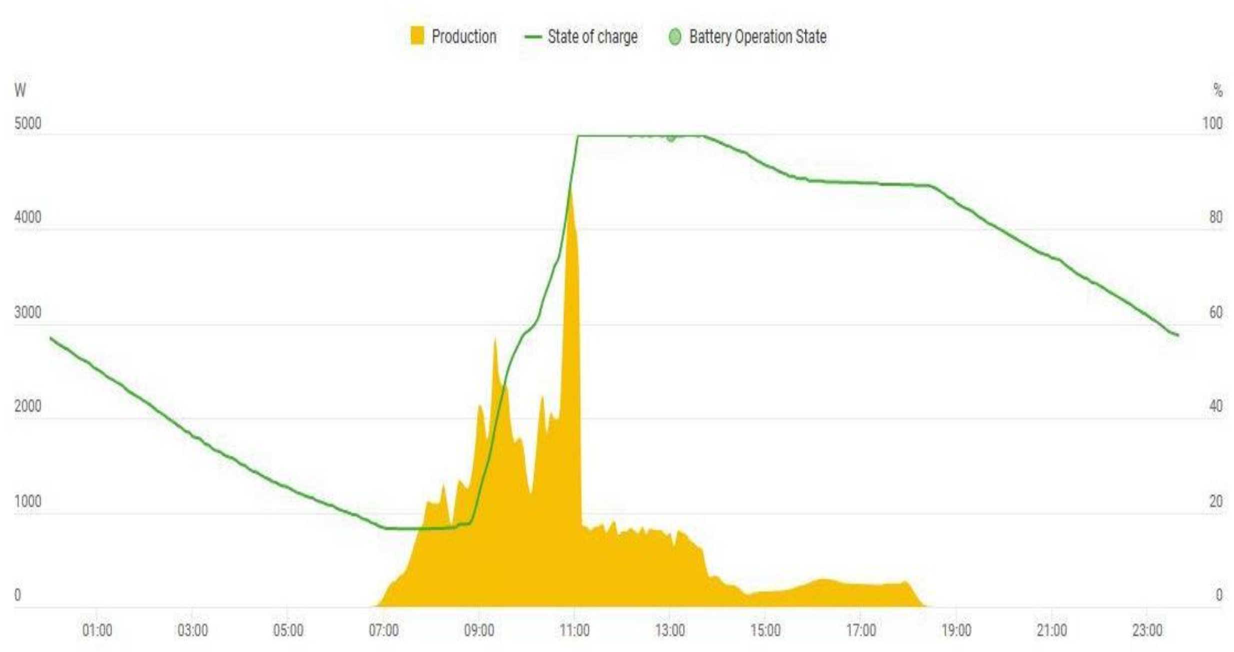


Figure 2 Kikambala Parish School system performance of solar energy generated, EV battery storage, charging and discharging.

1.2 The technical and economic viability of different second-life applications

The various case studies have demonstrated both technical and economic viability of the second-life application of repurposed EV batteries.

Technical Viability

Assessing the technical viability of repurposed EV batteries for second-life applications, key factors were evaluated which were battery state of health, safety and performance especially testing for thermal stability, identifying potential technical risks and ways to develop mitigation strategies and studying its operational efficiency which will go to inform the application of the repurposed EV battery which could be applications to maximise economic value.

The Kikambala Parish School project successfully repurposed EV batteries to deliver a stable power source for the school's operations. The technical assessment confirmed that existing battery technology could meet energy demands effectively, with the chosen design integrating seamlessly with the school's infrastructure. Implementation leveraged local resources, and the modular battery setup aligned well with the school's power needs. Operational processes were streamlined, with trained local personnel maintaining the system, ensuring the project's ongoing viability and supporting sustainable energy access in the educational environment. Similarly, the case studies in Amsterdam's Johan Cruyff Arena and the University of California, San Diego have demonstrated the technical viability of using repurposed EV batteries in second-life applications.

Economic Viability

Several aspects of economic viability should be explicitly defined, including setup costs, cost savings, market demand for the product, and income generation. The demand for electric vehicles is increasing rapidly, with sales estimated to reach 17 million by the end of 2024, resulting in an increased need for electric vehicle batteries. However, the transition to renewable energies to drive energy sector decarbonisation necessitates the use of energy storage devices. The degradation of EV batteries, especially in second markets, presents a greater challenge and hence may lead to several vehicles and batteries being retired. Electrical Review reported in 2024 that within the next five years (around 2029) set to see a significant increase in the volume of batteries retiring from a vehicle. These batteries provide a path based on the technical viability that can easily be integrated into renewable energy solutions for second-life application through repurposing. This reduces the pressure in mineral extraction and lowers the cost of manufacturing new batteries, and lower than the cost of recycling, which is currently not mature for cost-competitive mineral extraction. The total cost of a second-life battery varies between $40 and $160 per kWh (Madlener & Kirmas, 2017), depending on the ownership model and initial investment. In comparison, the cost of a new EV battery pack was $157 per kWh at the end of 2019 (Henze & BloombergNEF, 2019).

In conclusion, the implementation of second-life applications for EV batteries in Kenya is possible, supported by proven global technologies. Successful projects like the Johan Cruyff Arena and the Knights Energy initiative in Kikambala Parish School highlight the potential for a significant impact on Kenya's energy infrastructure. While economic viability varies, applications such as renewable energy storage and grid services can offer long-term cost savings, contributing to Kenya’s sustainable development despite initial investment challenges. Table 1 looks at the Techno-economic viability of repurposed batteries for different use cases, majorly informed by Knights Energy project to build a repurposed EV battery from Nissan Leaf batteries, with a focus on producing residential and institutional solutions such as the Kikambala Parish School.

Table 1 Techno-economic viability of repurposed batteries for different use cases.

Application	Technical Viability	Economic Viability
Renewable Energy Storage	High, proven technology with existing use cases globally.	Moderate to high, initial investment but long-term cost savings and grid efficiency.
Residential and Commercial Energy Storage	Highly scalable solutions are available.	Moderate, requires investment but reduces long-term energy costs.
EV Charging Stations	Existing technology can be adapted for second-life batteries.	A high, growing EV market increases demand and profitability.
Grid Services (Peak Shaving, Frequency Response)	High technology is well-established.	High, improves grid efficiency and reduces costs.
Microgrid and Island Power Solutions	High technology is suitable for remote and off-grid applications.	Moderate to high, significant initial costs, but essential for rural development.
Backup Power for Data Centres and Critical Infrastructure	High, critical for maintaining uptime in essential services.	High, high demand for reliable power in critical sectors.

Second-life applications for EV batteries in Kenya are technically viable and offer varying degrees of economic potential. Technologies like renewable energy storage, residential energy systems, EV charging stations, and grid services have proven effective globally, demonstrating high technical viability. While initial investments may be significant, the long-term benefits, such as grid efficiency, reduced energy costs, and support for rural electrification, are substantial. This presents a compelling opportunity for Kenya to enhance its energy infrastructure and promote sustainable development through the repurposing of EV batteries.

1.3 Potential second-life Applications for traction batteries in Kenya

Table 2 illustrates some of the many successful second-life applications in various European, American and Asian countries, demonstrating the potential for similar solutions in Kenya and across the African continent.

Table 2 Second Life Application of EV Batteries since 2012[3]

Company	Original Traction Application	Capacity	Year	Second-Life Application	Location
BMW	i3	22 or 33 kWh/pack	2016	Residential energy storage	Canada
Mercedes-Benz	Smart fortwo	12 MWh/13 MWh	2016	Recycling plant	Germany (Lünen)
Nissan	280 Nissan Leaf	5.6 MWh	2016	Back-up power	Netherlands (Amsterdam)
Volvo Group	Electric truck and bus batteries	200 kWh	2018	Residential SLB, Renewable energy	Germany, South Africa
Audi	e-tron		2020	Grid storage	Germany (Heilbronn)
GM	Baojun E100 and E200	250 kW/1 MWh	2020	Grid storage	China
Nissan, Tesla, Ford, Chevy	1,300 packs	28 MWh	2023	Grid services	United States (California)
Forsee	Forsee lithium nickel manganese cobalt oxide (Zen 4 and Zen 35)	40 MWh	2024	Grid storage	United Kingdom

Second-life applications for EV batteries in Kenya show great promise across various sectors. Key use cases include renewable energy storage, residential and commercial power solutions, EV charging stations, grid services, microgrids, and backup power for critical infrastructure. While each application presents unique benefits, such as grid stabilisation and rural electrification, they also face challenges like infrastructure needs and initial investments. Despite those challenges, the potential impact is high, particularly in enhancing energy management and supporting Kenya's renewable energy and EV adoption goals.

Evaluating existing global solutions, second-life applications for EV batteries in Kenya may hold exciting potential. Table 3 outlines various use cases, examining their benefits, challenges, and potential impact.

---

[3] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11033388/

Table 3 Benefits and challenges for in second life application of EV Batteries

Application	Benefits	Challenges	Potential
Renewable Energy Storage	Stabilising the grid and storing excess solar/wind energy.	This requires infrastructure and investments.	This has a high potential, due to Kenya's growing renewable energy sector.
Residential and Commercial Energy Storage	Providing backup power and reducing energy costs.	Initial setup costs and public awareness in repurposed EV batteries	Moderate to high, especially in urban areas.
EV Charging Stations	Supporting EV adoption and offering solar-assisted EV charging solutions.	Infrastructure development and maintenance.	This aligns with the government's push for EV adoption and the reduction of operational costs
Grid Services (Peak Shaving, Frequency Response)	Enhancing grid stability and managing demand fluctuations, especially during high peak hours	Requires integration with the national grid.	High, beneficial for Kenya's energy management.
Microgrid and mini-grids Power Solutions	Provides reliable power in remote areas.	High initial investment and logistical issues.	This holds a high potential, especially for rural electrification initiatives.
Backup Power for Data Centres and Critical Infrastructure	Ensures uninterrupted power supply.	Requires high reliability and security.	Moderate, important for economic and social infrastructure.

Kenya's vehicle market is driven by second-hand imports, making up 85% of car imports[4]. With this trend also extending to the EV sector, where used EVs, including Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), are prevalent due to their affordability and the absence of local manufacturing. These vehicles often arrive with reduced battery capacities, creating a demand for repairs and replacements within a few years of operation. This scenario presents opportunities for managing the end of life of those batteries with solutions such as battery repurposing in support of sustainable energy infrastructure and eventually to recycling, to promote circularity and e-waste management. Possible potential second-life applications for automotive traction batteries in Kenya can be:

1. **Residential, Institutional and Commercial Energy Storage:** Repurposed batteries can store energy from the grid and solar panels, providing backup power for homes, and businesses, especially in areas with unreliable electricity.
2. **Mini-Grids and Off-Grid Solutions:** Second-life batteries can be used in mini-grid systems to support electrification in remote areas, balancing power supply from renewable sources.
3. **Backup Power Systems:** They can serve as backup power sources for essential and/or critical infrastructure like hospitals, data centres, schools, and telecommunications.
4. **Electric Mobility Infrastructure:** These batteries can support charging stations for electric motorcycles, tuk-tuks, and small EVs, facilitating a more sustainable transportation network.
5. **Agricultural Applications:** Batteries can power irrigation systems, cold storage, and processing equipment in agricultural areas, enhancing productivity and reducing post-harvest losses.

---

[4] Trends and Insights for Africa, 2020

2. Second-Life Battery Pack Analysis

2.1 Critical electro-technical parameters for evaluating battery suitability for second-life applications.

Evaluating the suitability of an EV battery for second-life applications is crucial because it ensures that the battery can perform safely and efficiently in its new application. Key parameters, such as degradation conditions, capacity, and power output, determine whether a battery is fit for reuse in energy storage or other applications. Testing at the cell, module, or pack level helps assess the remaining lifespan, while economic viability ensures that the repurposed battery offers a cost-effective solution. This evaluation also minimises waste and maximises resource utilisation. When evaluating the suitability of an EV battery for second-life applications, the following parameters are considered:

- Degradation conditions (energy, power, external wear).
- Requirements for different applications and configurations.
- Economic viability of the workable solutions.
- Second life potential is estimated using the following parameters.
    - Data collected throughout the first life is used to continually estimate the battery health, or
    - Testing the capacity and internal resistance at pack level, module level or cell level.
- In the technical evaluation stage, the capacity (maximum energy storage capacity), maximum power (possible C-rate), weight, volume limitations, energy management system (EMS), thermal management and possible configurations are analysed.
- The economic evaluation in terms of cost of each potential solution and revenue potential is assessed using the different financing models available and potential useful life of the repurposed battery.

Figure 3 Knights Energy Engineer Disassembling a Nissan Leaf Battery Pack

2.2 Standardised testing procedures for assessing battery health and performance.

Standardised testing procedures for assessing battery health and performance are crucial because they provide a consistent and reliable framework for evaluating the safety, capacity, and efficiency of batteries. These procedures ensure comparability across different batteries, helping manufacturers, regulators, and consumers trust the performance claims. They also help in identifying potential issues early, optimising battery life, and supporting the development of second-life applications. By following standardised tests, industries can improve product quality, reduce waste, and promote sustainability in battery repurposing and recycling efforts. The following methods are used for assessing battery health and performance.[5]

- **Full charge-discharge cycle**s, where individual modules/cells are charged, discharged, and charged back up while keeping track of their capacity. This then informs for which areas of application they are most suited.
- **Internal Resistance Method**, where the age of a module/cell is determined using its internal resistance measured at the time. The evolution of the resistance according to the discharge cycles should be previously known.
- **Open Circuit Voltage Measurement**, where different current pulses are applied while measuring the relaxation time of the modules/cells.
- **Self-discharge Test**, where a module/cell is disconnected from an electrical circuit and its voltage level measured over a certain period.
- **Statistical approach**, where the capacity and impedance distribution of cells is investigated within a battery pack.
- **Machine learning methods**, based on a large set of data for training.

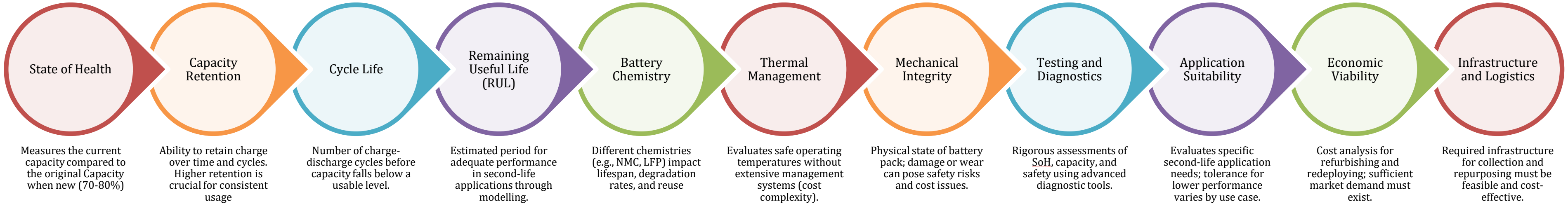
2.3 Criteria for determining the feasibility of reusing batteries for second-life applications.

As the demand for sustainable energy solutions grows, the repurposing of electric vehicle (EV) batteries for second-life applications has gained significant attention. To effectively evaluate the feasibility of such applications, a comprehensive set of criteria is essential. These criteria encompass various aspects of battery performance and condition, including state of health, capacity retention, cycle life, and economic viability. By systematically assessing these factors, stakeholders can determine the suitability of batteries for new roles in energy storage, grid stabilisation, and other applications, contributing to a circular economy and reducing waste in the battery lifecycle.

Figure 4 Battery Testing in Progress

---

[5] Cepisca, C et al Comparative study of screening methods for second-life LIFEPO4 batteries



State of Health

Measures the current capacity compared to the original Capacity when new (70-80%)

Capacity Retention

Ability to retain charge over time and cycles. Higher retention is crucial for consistent usage

Cycle Life

Number of charge-discharge cycles before capacity falls below a usable level.

Remaining Useful Life (RUL)

Estimated period for adequate performance in second-life applications through modelling.

Battery Chemistry

Different chemistries (e.g., NMC, LFP) impact lifespan, degradation rates, and reuse

Thermal Management

Evaluates safe operating temperatures without extensive management systems (cost complexity).

Mechanical Integrity

Physical state of battery pack; damage or wear can pose safety risks and cost issues.

Testing and Diagnostics

Rigorous assessments of SoH, capacity, and safety using advanced diagnostic tools.

Application Suitability

Evaluates specific second-life application needs; tolerance for lower performance varies by use case.

Economic Viability

Cost analysis for refurbishing and redeploying; sufficient market demand must exist.

Infrastructure and Logistics

Required infrastructure for collection and repurposing must be feasible and cost-effective.

Figure 5 Criteria for determining the feasibility of reusing batteries for second-life applications.

2.4 Battery re-design to accommodate other modules (chemistry/form-factor)

Repurposing batteries for second-life applications often involves dismantling existing battery packs into modules, which are then used to design new battery packs suited for various use cases. This requires creating a modular and flexible design that accommodates different chemistries, sizes, and connection interfaces while ensuring effective thermal management and safety. The redesign must adhere to relevant standards and be adaptable to future advancements in battery technology. Key considerations include modularity for easy swapping, versatile electrical and thermal management systems, and robust safety features. Extensive testing and cost-efficient assembling processes are essential for scalability and integration with existing systems, ensuring that the redesigned batteries meet performance and safety requirements across diverse applications. A good example is a pilot repurposed battery pack named GreenCell by Knights Energy.

Figure 6 The Assembly of the GreenCell

GreenCell is a repurposed 2.4 kWh EV battery derived from a 2010 Nissan Leaf's original 24 kWh battery pack, which has degraded to 34.9% of its initial capacity over time. As part of the repurposing process, the battery pack was meticulously dismantled, and its 48 modules underwent comprehensive testing.

Fourteen modules with optimal characteristics were selected and reassembled to create the new 2.4 kWh battery pack. The remaining modules were categorised based on their suitability for second-life applications. Modules deemed viable were earmarked for reuse in new battery assemblies designed for secondary applications. Conversely, modules found unsuitable for second-life use were securely stored in isolated areas to prevent contact with metals and ensure safe handling.

Maintaining an adequate stock of unusable modules is critical for facilitating the recycling process, emphasising sustainability and waste management within the EV battery lifecycle. Table 4 provides a sample of the test results for the modules.

Table 4 The characteristics of the modules selected for assembly of the GreenCell.

Module Ref. No.	Parallel Cells No.	Capacity (Ah)	Internal Resistance (mΩ)	Voltage (V) on 10/07/24	Voltage (V) on 17/07/24
1	1	26.62	2.15	4.052	4.0516
	2	26.14	2.1	4.0501	4.0496
2	1	27.68	2.14	4.0556	4.0534
	2	28.17	2.14	4.0497	4.0487
4	1	26.52	2.19	4.0609	4.0604
	2	27.45	1.88	4.0631	4.0625
5	1	27.68	2.26	4.0551	4.0538
	2	26.09	1.91	4.0541	4.0535
8	1	27.23	2.12	4.0521	4.0512
	2	26.77	2.02	4.0503	4.0498
9	1	27.99	2.3	4.0561	4.0555
	2	27.03	2.31	4.0553	4.0547
10	1	26.48	2.18	4.0522	4.0512
	2	26.05	1.97	4.0499	4.0487
12	1	26.92	2.05	4.0569	4.0559
	2	26.25	2.07	4.0527	4.0519
16	1	28.2	2.02	4.0562	4.0551
	2	27.85	2.02	4.0499	4.048
19	1	26.80	2.14	4.0532	4.0521
	2	26.50	2.36	4.0512	4.0493
23	1	27.32	2.04	4.0689	4.0647
	2	27.35	2.08	4.0692	4.0671
24	1	26.64	2.14	4.0613	4.0609
	2	26.77	2.11	4.0612	4.0597
28	1	28.07	2.14	4.0496	4.0482
	2	26.71	2.14	4.0551	4.0537
48	1	27.13	2.17	4.0493	4.0478
	2	26.17	2.13	4.0468	4.0453
Discharge pack resistance = 0.138 Ohms (BOL), 0.341 Ohms (EOL)[6]					
Average Internal Resistance (mΩ) at Beginning of Life			1.4375		
Average Internal Resistance (mΩ) at End of Life			3.552		

The findings of the tests conducted on all 96 cell pairs within the 48 modules of the Nissan Leaf Battery Pack that were disassembled for the study were as follows:

The capacities of all parallel cell pairs range from 23.04 to 28.41 Ampere-hours, with an average capacity of 26.27 Ampere-hours for the entire battery pack. This capacity test indicates that the pack is operating at approximately 34.9% State of Health (SOH), which corresponds to the lowest measured capacity of 23.04 Ampere-hours compared to the original capacity of 66 Ampere-hours.

The internal resistances of the cells vary between 1.88 and 2.81 milliohms. This range is acceptable when compared to the OEM's specified operating range: 1.44 milliohms (calculated as 138 milliohms divided by 96 cell pairs) at the Beginning of Life, and 3.55 milliohms (341 milliohms divided by 96 cell pairs) at the End of Life. All cells remain within this acceptable internal resistance range.

It is important to note that higher internal resistance can lead to energy loss and increased heating during operation, which may further accelerate cell degradation.

---

[6] Sura, 2010 Nissan Leaf. Battery Design

The assembled battery consists of selected modules configured to a nominal voltage of 51.2 V and a capacity of 52 Ah, totalling 2.66 kWh. The assembly process involved selecting 14 modules with similar State of Health (SOH) from a test group. These modules were paired and connected in parallel, effectively doubling the capacity from 26 Ah to 52 Ah. Each module is designed with a 2-series, 2-parallel configuration, which enhances both Ampere-hour and voltage capacity.

The repurposed battery pack features a 2-series, 4-parallel configuration, providing each module pair with an effective nominal voltage of 7.3 V and a capacity of 52 Ah. To achieve the overall pack voltage of 51.2 V, seven parallel module pairs were connected in series.

For mechanical integrity, the modules are secured together using 8-millimetre diameter metal rods, which bolster the pack's structural strength. A Smart Battery Management System (BMS) is integrated into the assembly, with electrical leads connected to each cell to monitor individual cell voltages. Additionally, two temperature sensors are deployed to continuously assess the temperature of the battery pack. The BMS protects the cells by ensuring they operate within prescribed voltage, current, and temperature ranges, while also maximising the pack's service life by maintaining cell voltages within a few millivolts of each other. Users can set operating parameters via a smartphone application programmed into the BMS.

The assembled battery pack is housed within a custom-built metallic enclosure, with internal surfaces lined with insulating material to prevent electrical short circuits. A monitoring display and an emergency ON/OFF switch are conveniently located on the front of the enclosure, allowing for real-time monitoring of battery parameters during operation. For enhanced safety, the battery terminals for load connection are situated in a separate compartment at the top of the enclosure.

While the GreenCell repurposed battery demonstrates an effective assembly process, it overlooks several critical aspects, particularly with different EV models. Some of these key considerations include:

Chemistry Differences: Different EV manufacturers may use varying battery chemistries, such as lithium-ion, nickel-metal hydride, or solid-state batteries. Each chemistry has unique characteristics in terms of energy density, cycle life, thermal stability, and charge/discharge rates. This variability can impact not only performance but also safety and longevity when modules from different chemistries are combined.

Figure 7 The 6.8 kWh GreenCell repurposed battery derived from a 2010 Nissan Leaf

Module Size Variability: The physical dimensions and configurations of battery modules can differ significantly across EV models. For instance, module sizes may affect the overall design of the battery pack, including space constraints within the vehicle, heat dissipation, and electrical connections. Using modules of varied sizes in a single assembly can lead to inefficiencies and complications in integration.

Compatibility Challenges: The integration of battery modules from different EVs introduces compatibility challenges. These include ensuring that the electrical characteristics (voltage and current ratings) align, as well as making certain that thermal management systems can adequately support the different module types. Furthermore, mismatches in charging protocols and Battery Management System (BMS) configurations can lead to operational issues and reduce the overall reliability of the battery pack.

Standardization Needs: To address these compatibility challenges, there is a growing need for industry standards regarding battery chemistries and module sizes. Standardization could facilitate the interchangeability of components, enhance recycling efforts, and promote broader adoption of battery technologies across different EV platforms.

In summary, while the presented example provides a solid foundation for battery assembly, addressing the compatibility issues associated with different battery chemistries and module sizes is crucial for the development of efficient, safe, and reliable battery systems in the evolving EV market.

2.5 Analysis of system components, local sources of components, performance, and safety considerations

This analysis highlights the critical aspects of component selection, performance optimization, and safety assurance in the assembly of the battery pack. Proper sourcing and assembly, coupled with robust monitoring and protection mechanisms, are key to ensuring reliable and safe operation of repurposed batteries.

Electric vehicle (EV) battery structures incorporate various cell types, each with unique characteristics. Cylindrical cells are known for their durability and reliable thermal properties, making them common in many modern EVs. Prismatic cells are space-efficient and provide high capacity, though their thermal management can be more complex. Pouch cells, while lightweight and flexible, lack rigid enclosures, making them susceptible to swelling and requiring careful handling.

The transition from individual cells to modules and complete battery packs involves integrating these cells with electrical connections and thermal management systems. Modules are often wired with intricate connections to ensure performance, and cooling mechanisms like liquid cooling or passive heat management systems are embedded to regulate temperatures during operation.

Repurposing used EV batteries poses challenges, particularly in disassembly. Extracting cells or modules requires precise handling due to safety risks and integrated components. Second-life applications typically target module-level repurposing, as reusing at the cell level necessitates extensive reconfiguration and adherence to stringent safety protocols. Additionally, thermal management systems designed for the original application may need to be modified or removed when adapting batteries for new uses, which is vital to prevent overheating. Electronic components, such as Battery Management Systems (BMS) and wiring harnesses, often require re-engineering or replacement to suit the new application context, further complicating repurposing efforts.

Overall, transitioning batteries from primary use to second-life applications requires balancing technical complexity, safety, and cost-effectiveness.

2.5.1 Local Sources of Components

i. *Battery Modules*: Sources include the decommissioned EV battery packs such as the Nissan LEAF model which has been used for this study or can be sourced from other local firms specialising in lithium-ion batteries.
ii. *Metal Rods and Enclosure Materials*: Local hardware shops can provide the necessary rods and materials for constructing the enclosure. Standard metalworking shops can supply 8 mm diameter rods and sheet metal for the enclosure. Fabrication of enclosures can be outsourced to specialised metal fabricators or done internally by specially trained welding personnel.
iii. *Battery Management System (BMS)*: Smart BMS units can be purchased from electronics suppliers or specialised battery component retailers. It is also possible to design and manufacture specialised BMS.
iv. *Insulating Materials:* These can be sourced from local hardware stores or suppliers of electrical insulation products.
v. *Monitoring Display and Switches*: These components can be sourced from local electronics stores or suppliers of industrial control equipment.

2.5.2 Performance Considerations

i. *Energy Density*: The assembled battery pack provides 2.66 kWh, which is suitable for small to medium-scale energy storage applications like running essential loads in a household or an office, like lighting, internet routers and infotainment systems. The 51.2 V nominal voltage is ideal for many renewable energy systems and light-duty electric mobility applications.
ii. *Cycle Life*: The use of a BMS to maintain cell balance and monitor voltage and temperature enhances the cycle life of the battery pack. The cycle life will also depend on the quality of the modules used and their history if they are second-life batteries.
iii. *Efficiency*: The parallel and series configuration is designed to optimise energy delivery while maintaining safe operating conditions. The BMS ensures that each cell operates within optimal voltage ranges, reducing energy loss due to imbalances.
iv. *Thermal Management:* The inclusion of temperature sensors allows for real-time monitoring of the battery pack's temperature, ensuring that it operates within safe limits and preventing thermal runaway.

2.6 Leveraging European Second-Life Battery Pack

The betterPack, developed by Betteries AMPS GmbH, exemplifies a repurposed EV battery in Europe, with product specifications that comply with European standards. This product offers a comparative analysis against the locally developed GreenCell, highlighting differences in product design, regulatory frameworks, and practical applications between the two regions. Additionally, it provides comprehensive guidelines on general instructions, safety precautions, tooling and equipment, housing pre-assembly, side covers and casings, BMS assembly, and EOL testing.

The betterPack battery system features a "click and go" design for seamless integration, eliminating the need for cumbersome cabling. Its modular architecture allows for the stacking of battery modules, thereby enhancing energy capacity and offering adaptability through standardised packs and tailored application modules. The innovative battery management system (BMS), specifically engineered for second-life cells, optimises battery life and ensures efficient performance. The system is housed in a robust, IP65-rated marinized casing, providing durability and water resistance suitable for various environments.

Additionally, the system has an integrated GSM and Wi-Fi connectivity, linking to the proprietary Betteries cloud platform. This enables real-time monitoring of battery usage and performance, enhancing safety through continuous oversight. Remote updates and fleet management are facilitated through over-the-air capabilities, ensuring that the system remains up-to-date and functional. Furthermore, advanced AI and machine learning analytics are employed to predict and enhance the performance and lifespan of the batteries, providing a comprehensive solution for second-life applications.

Figure 8 The SUNRISE 3000 kit betterPack by betteries

The betterPack battery system offers significant advantages, particularly highlighted by its involvement in various projects and its innovative stacking capabilities developed by Betteries. Notably, betterPack has been instrumental in the SOLUTIONSplus e-mobility projects in Hanoi, Pasig, and Lalitpur/Kathmandu, where it provides swappable 48V second-life batteries. These initiatives aim to decarbonise mobility and showcase the benefits of a circular economy. The betterPack has undergone rigorous certification and validation, earning CE, UN, and IEC certifications, which affirm its reliability and suitability for diverse applications, including powering small electric vehicles and providing intermittent battery storage for e-bike charging hubs.

Figure 9 Betteries betterPack Application in electric mobility[7]

Its modular design allows for the stacking of battery modules to enhance energy capacity, scaling from 2.3 kWh to 9.2 kWh. This scalability makes betterPack adaptable for a wide range of uses, from small-scale mobile power solutions to larger energy storage needs. Furthermore, the betterPack contributes to sustainability by giving electric vehicle batteries a second life, thereby reducing the carbon footprint and the need for new battery production. These features collectively position the betterPack as a versatile and sustainable solution, supporting the transition to renewable energy and promoting environmental sustainability. The images below represent the local assembly of the betterPack to achieve a 1.2 kWh battery pack.

Figure 10 Assembly of the betterPack

---

[7] Source: betteries AMPS GmbH

The GreenCell and betterPack represent two innovative solutions for repurposing electric vehicle (EV) batteries for second-life applications. Here's a comparison based on their design, functionality, and applications

Table 5 Comparison between the GreenCell and the betterPack

Criteria	GreenCell	betterPack
Battery Origin	Repurposed from EV batteries, developed by Knights Energy	Repurposed from EV batteries, developed by betteries AMPS GmbH.
Energy Management System (BMS)	Smart BMS that monitors individual cell voltages and temperatures, ensuring safe operation.	Advanced BMS with AI and machine learning, optimized for second-life cells, and remote monitoring.
Thermal Management	Temperature sensors integrated for real-time monitoring.	IP65-rated marinized casing for durability and water resistance, integrated thermal management.
Communication and Monitoring	Basic monitoring via a display, emergency ON/OFF switch, and smartphone app for setting parameters.	GSM and WiFi connectivity, real-time monitoring via a proprietary cloud platform, remote updates.
Physical Enclosure	Custom-built metallic enclosure with insulating material and emergency shut-off.	Robust, IP65-rated casing suitable for various environments, especially for outdoor use.
Safety Features	BMS protects against voltage, current, and temperature issues.	CE, UN, IEC certified; real-time performance monitoring; over-the-air updates; fleet management.
Applications	Suitable for small-scale energy storage like residential essentials	Small scale and can be stacked to large scale energy applications and e-mobility projects (e.g., Hanoi, Pasig, Lalitpur) and provides intermittent storage for e-bike charging hubs.
Certifications and Standardization	No specific certifications.	CE, UN, IEC certifications for reliability and safety.
Modular Design & Flexibility	Uses selected modules, not optimized for cross-manufacturer module compatibility.	Modular, stackable design with adaptable configurations for a wide range of applications.
Target Markets	Small to medium-scale applications, such as residential	E-mobility, renewable energy storage for small to medium scale applications, and small electric vehicles

Figure 11 The Assembled betterPack

Both the GreenCell and betterPack offer valuable second-life solutions for EV batteries, contributing to sustainability by repurposing used EV batteries. However, the betterPack stands out due to its modular design, scalability, advanced Battery Management System (BMS), and comprehensive regulatory certifications, making it highly adaptable and versatile for a wide range of applications. In contrast, the GreenCell focuses on a more specific, localised approach, primarily repurposing existing Nissan Leaf battery modules for smaller energy storage solutions. While this is effective for targeted applications, the GreenCell faces challenges in terms of module compatibility and scalability across different EV battery chemistries and sizes.

To enhance its effectiveness, GreenCell could consider adopting some of betterPack's best practices, such as integrating a more flexible, standardised modular design that can easily accommodate different EV battery chemistries and configurations. Additionally, enhancing the BMS to incorporate advanced features for real-time monitoring and remote diagnostics could improve the overall efficiency and longevity of the repurposed battery packs. Lastly, pursuing regulatory certifications, like betterPack's CE, UN, and IEC approvals, would help ensure the GreenCell’s solutions are widely recognised for safety and reliability, expanding its market potential and supporting the long-term viability of second-life battery systems.

3. Second-Life Battery Implementation

3.1 Battery Reuse Value Chain in Formal and Informal Sectors.

In the battery reuse value chain, both the formal and informal sectors play critical roles, each with distinct operations, practices, and impacts. By understanding the operations of both sectors, stakeholders can better manage the challenges and opportunities within the battery reuse value chain, leading to more sustainable and efficient practices.

3.1.1 Formal Sector Operations

The formal sector in the battery reuse value chain typically involves regulated and structured businesses, companies, and organisations that operate under legal frameworks and industry standards. Their operations are characterised by:

i. Battery Collection and Assessment

   The formal sector sources batteries from EV manufacturers, automotive workshops, recycling centres, and consumers. These batteries are then assessed and evaluated for capacity, voltage, internal resistance, and thermal characteristics, with safety checks conducted to determine their state of health (SoH) and suitability for second-life or end-of-life applications. Comprehensive documentation is maintained, recording the battery's origin, performance metrics, and ownership details to ensure traceability and compliance with regulatory standards.

ii. Battery Refurbishment and Repurposing

   Batteries are carefully disassembled to address any defective cells through replacement or reconfiguration. The modules or cells are then reassembled into new configurations, making them suitable for various second-life applications, such as stationary energy storage or low-demand mobility uses. To ensure quality, stringent testing is conducted to verify that the reconfigured batteries meet all required safety and performance standards before they are reintroduced into the consumer market.

iii. Manufacturing and Integration

   Refurbished cells or modules are assembled into new battery packs, equipped with modern Battery Management Systems (BMS) and secured within protective enclosures. These refurbished battery packs are then integrated into various products, such as battery energy storage systems, uninterruptible power supplies (UPS), and electric vehicles designed for lower energy demands.

iv. Sales and Distribution

   The formal sector distributes refurbished batteries through official retail channels, offering warranties and after-sales support to customers. Additionally, these sector players ensure full compliance with environmental regulations, adhere to safety standards, and maintain proper labelling and certification for their products.

v. Recycling and Disposal

   Batteries that reach the end of their usable life are stored under regulated conditions until they are directed to certified recycling facilities, where valuable materials like lithium, cobalt, and nickel are recovered. Non-recoverable components are disposed of in compliance with environmental regulations to ensure minimal impact on the environment.

3.1.2 Informal Sector Operations

The informal sector consists of unregulated or loosely regulated entities that operate outside official channels. This sector is prevalent in regions with limited access to formal recycling infrastructure. Key characteristics of the informal sector include:

i. Battery Collection and Salvage

The informal sector typically sources batteries from scrapyards, local repair shops, and consumers. Salvaging involves manually dismantling batteries to extract usable cells or materials, often conducted without appropriate safety precautions. Testing methods are basic and rudimentary, relying on visual inspection and simple voltage checks to assess cell usability.

ii. Battery Refurbishment and Repurposing

Usable cells are reassembled into new battery packs without standardised configurations or proper integration of Battery Management Systems (BMS), a process known as ad hoc reassembly. Repairs are conducted manually using available tools, which often results in inconsistent quality and compromised safety standards. Additionally, there is little to no documentation maintained regarding the origin, performance, or safety of these repurposed batteries.

iii. Sales and Distribution

Informal sector batteries are sold in local markets at lower prices, often lacking warranties or any form of quality assurance. These batteries are typically distributed through second-hand sales channels, including street vendors and unregulated online platforms. The informal sector operates without adhering to safety, environmental, or regulatory compliance standards.

iv. Recycling and Disposal

Informal recyclers often employ crude methods, such as acid baths or open-air burning, to extract valuable materials from used batteries, posing serious risks to human health and the environment. These unsafe practices can result in the improper disposal of non-usable components, causing significant environmental contamination, including soil and water pollution.

v. Worker Safety and Health

Workers in the informal sector often face unsafe working conditions, with limited access to protective gear, exposing them to health risks from toxic chemicals and physical injuries due to improper battery handling. Additionally, there is a general lack of formal and specialised training in managing hazardous materials, which increases the likelihood of accidents and contributes to long-term health issues.

3.1.3 Comparative Analysis of Formal and Informal Sector

The formal sector places a strong emphasis on quality and safety, adhering to industry standards to ensure reliable and secure battery handling. In contrast, the informal sector often compromises on these aspects to reduce costs and speed up processes. Environmentally, the formal sector engages in responsible recycling and disposal practices, while the informal sector's methods frequently harm the environment due to poor handling. Economically, the formal sector fosters sustainable, well-paying jobs, whereas the informal sector often relies on low-wage labour. Regulatory compliance is maintained in the formal sector, unlike the often unregulated and legally problematic informal practices.

3.2 Skills Gap Analysis

The electric vehicle industry continues to grow exponentially in Kenya. According to NTSA data, 5,294 EVs were registered in 2024 (excluding e-bicycles, which are not registered). In a scenario with strong policy support, it is projected that over 800,000 electric vehicles could be on Kenyan roads by the end of 2028.

Achieving the government's target of 5% of all new vehicle registrations being electric by 2025 would only be possible under this high support scenario, with around 27,000 new electric vehicle registrations. Comparatively, moderate policy support would result in 14,000 new registrations, and under low support, only 8,000 would be expected.[8] Figure 12 shows the growth of new electric vehicle registration statistics by vehicle classification (2018 - 2024).[9]

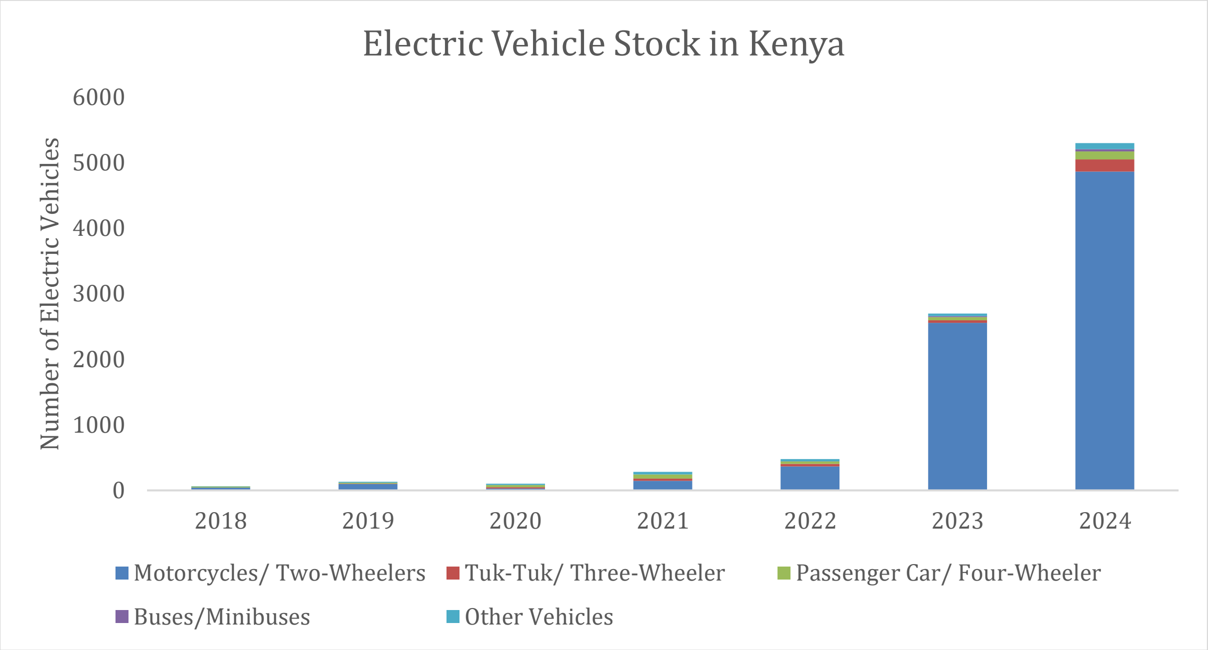


Figure 12 New electric vehicle registration statistics by electric vehicle classification (2018 - 2023) (Source EMAK)

The transition to a sustainable economy through the repurposing of electric vehicle (EV) batteries for second-life applications presents a significant opportunity for economic growth, job creation, and environmental sustainability. However, realising these potential hinges on developing a skilled workforce and enhancing workshop tooling throughout the EV value chain.

As novel technology vehicles enter the market, it is crucial to analyse numerous factors that influence this transition. A workforce equipped with specialised skills in EV technologies is essential. Technicians will need to develop advanced competencies in areas beyond traditional EV maintenance,

---

[8] EMAK Electrifying Kenya's Transportation Sector

[9] Source NTSA

specifically tailored to second-life applications. Key skills include:

1. Electrical Engineering to understand battery design and integration for new applications.
2. Electronics proficiency in working with complex electronic systems in EVs.
3. Battery Storage Systems and Battery Management Systems (BMS), knowledge of how to monitor and optimise battery performance.
4. Computer Programming skills in software development for diagnostics and monitoring systems.
5. Health and Safety Training, ensuring safe handling of high-voltage components and compliance with safety standards.
6. Environmental Regulations and Compliance: familiarity with regulations governing battery repurposing and disposal.

To effectively manage these skills, the following specialised tools and equipment will be necessary:

1. Tools for Handling High-Voltage Circuits, including insulated tools designed for battery maintenance.
2. Battery Analysers and Cell-Level Diagnostics to assess battery health and performance.
3. High-Voltage Testers for safely evaluating battery systems.
4. Diagnostic Software, which varies by EV model, is crucial for accurate assessments.
5. Onboard Diagnostic Tools, which are Essential for troubleshooting and performance optimisation.
6. Facilities for Battery Assembly and Manufacturing, which are necessary for repurposing activities.
7. Capabilities for Raw Material and Recycled Material Refining: To support sustainable sourcing for new applications.

Additionally, enhancing R&D investment in EV battery technology, improving supply chains for necessary raw materials, and establishing reliable infrastructure for heavy manufacturing, such as consistent power and communication networks, are vital. Effective waste management strategies and formal recycling programs will facilitate the accumulation of battery stock for future second-life and end-of-life management, ensuring the safe handling, transport, and disposal of used EV batteries.

Figure 13 Knights Energy Battery Lab

Addressing these skills and infrastructure needs will not only build capacity but also promote circularity within the second-life EV battery value chain. This effort requires collaboration among stakeholders, including Academia from both Universities and Technical and Vocational Education and Training (TVET) institutions, Industry Players and Government and Regulatory Bodies.

Currently, the availability of EV training programs in the country is limited, focusing primarily on battery dismantling, testing, and fabrication. However, to effectively support second-life applications, training must encompass a broader range of skills and knowledge areas. Programs should address not only technical skills but also innovative approaches to integrating repurposed batteries into new applications, such as renewable energy systems, off-grid solutions, and energy storage for commercial and residential use.

The most recognised technical training options are provided by AfricaNEV and AMC EV in Nairobi, offering a one-week course with both online and in-person sessions for a fee of USD 308.71. To meet the demands of a rapidly evolving industry, it is essential to expand and diversify these educational offerings. Training should include modules on system integration, sustainable design principles, environmental impact assessment, and effective waste management strategies. By doing so, we can cultivate a workforce equipped to maximise the potential of second-life battery applications, driving economic growth and environmental sustainability in the process.

3.3 Potential risks and challenges associated with implementing second-life applications in Kenya.

Managing second-life batteries presents unique challenges compared to first-life batteries. The primary challenge is obtaining comprehensive battery history information, including manufacturing details, use cases, and prior assessments, due to the diverse sources of second-hand vehicles. The primary issue lies in the varying states of health within a battery energy storage system, where some modules may retain higher capacity while others have significantly lower capacity. This imbalance necessitates meticulous management to prevent overall performance degradation. Additionally, identifying and isolating end-of-life modules is critical to maintaining system integrity, requiring advanced management beyond standard models. These challenges highlight potential risks and difficulties in implementing second-life EV battery applications in Kenya, including:

- **Technical Barriers**: Assessing the health and remaining capacity of used batteries can be complex, especially with non-standardised battery designs, sizes, capacities, and configurations, which could lead to mismatches in energy storage systems.
- **Lack of Standardisation**: The diverse designs, sizes, and chemistries of batteries complicate repurposing efforts and increase costs.
- **Economic Viability**: When assessing the viability of battery repurposing, it is crucial to consider cost factors, which include the impact of different configurations on the overall cost. For instance, configurations requiring extensive disassembly (cellular level) tend to incur higher costs. As the cost of new batteries and other storage options decreases and repurposing costs rise, the economic feasibility of repurposing may become increasingly challenging, particularly in the future.[10]
- **Safety Concerns**: Ageing batteries pose risks, such as fire hazards or chemical leaks, if not effectively managed during repurposing and application.

---

[10] Lumkong & Davis, Electric Vehicle Battery Repurposing and Second Life.

- **Regulatory and Infrastructure Gaps**: The absence of comprehensive regulations for second-life battery uses and a lack of robust infrastructure for battery collection, assessment, and repurposing impede implementation.
- **Environmental Impact**: Without proper end-of-life management, second-life applications could contribute to e-waste if batteries are not correctly disposed of and prepared for recycling after their second life.
- **Market and Consumer Acceptance**: There may be scepticism about the reliability and safety of second-life batteries, affecting market uptake and consumer trust.

3.4 Mitigation strategies and risk management recommendations for battery implementation.

By developing robust mitigation strategies and risk management practices, such as advanced battery diagnostics, regulatory collaboration, and stakeholder engagements, those risks and challenges can be effectively addressed hence capitalising on the benefits of second-life battery applications. Table 6 looks at the different risks and the proposed mitigation strategies and recommendations.

Table 6 Risks with proposed mitigation strategies and recommendations.

Risks and Challenges	Mitigation Strategies & Risk Management Recommendations
Technical Barriers	Developing standardised battery assessment protocols and investing in advanced diagnostic tools to accurately evaluate battery health and capacity before and after repurposing.
Lack of Standardisation	Collaborations with international organisations to develop and adopt standardised designs, sizes, and chemistries for batteries to streamline repurposing processes and best practices.
Economic Viability	Conducting cost-benefit analyses and exploring subsidies or incentives to offset repurposing costs. Investing in R&D activities will improve the efficiency and cost-effectiveness of second-life applications.
Safety Concerns	Implement rigorous safety protocols and continuous monitoring systems to detect and isolate ageing batteries at risk of failure. Conduct regular training of technicians on handling second-life batteries in a controlled environment before being deployed to the consumer market.
Regulatory and Infrastructure Gaps	Working with government agencies to develop comprehensive regulations for second-life battery use and establishing infrastructure and mechanisms for efficient battery collection, assessment, repurposing, and recycling.
Environmental Impact	Ensure proper end-of-life management by establishing clear guidelines for recycling and disposal after the second life. This will promote circular economy practices to minimise e-waste.
Market and Consumer Acceptance	Launching awareness campaigns and expos to educate consumers on the benefits and safety of second-life batteries. Providing warranties or incentives to build trust and encourage market adoption.

Therefore, implementing second-life EV battery applications presents significant risks and challenges, including technical barriers, safety concerns, economic viability, and regulatory gaps. The primary technical challenge is managing the varying state of health and energy capacity of used batteries, which requires advanced diagnostics and standardisation measures. Economic hurdles include the cost competitiveness advantage of repurposing, compounded by the increasing affordability of new batteries. Safety concerns, regulatory gaps, and market acceptance further complicate implementation. Addressing these challenges requires robust mitigation strategies, including developing standards, enhancing infrastructure, and fostering consumer trust through education and incentives.

4. Battery Safety Handling & Transportation

4.1 Safety procedures for handling second-life batteries.

Handling second-life batteries requires careful attention to safety procedures due to the potential risks associated with their use, including electrical hazards, chemical exposure, and thermal runaway. Implementing these safety procedures helps mitigate the risks associated with handling second-life batteries and ensures a safer working environment.

Key safety procedures for handling second-life batteries include:

Personal Protective Equipment (PPE)

- *Gloves:* Use Class 0 insulated gloves to prevent electric shock and chemical exposure.
- *Safety Goggles:* Protect eyes from potential splashes of electrolyte or battery venting.
- *Fire-Resistant Clothing:* Wear clothing that can resist fire in case of thermal incidents.
- *Respirators:* Set up a safe and secure testing point. In case of potential exposure to harmful gases or fumes, wear appropriate respiratory protection.

Inspection and Testing

- *Visual Inspection:* Check for physical damage, swelling, corrosion, or leakage before handling which also include checks on the pack interconnections.[11]
- *Electrical Testing:* Verify the voltage and state of charge (SoC) to ensure the battery is within safe operating limits.[12]
- *Capacity Testing:* Perform tests to assess the remaining capacity and overall health of the battery to determine suitability for reuse.

Handling and Transportation

- *Use Insulated Tools (1000 VDC):* Always use insulated tools to prevent accidental short circuits.
- *Avoid Dropping:* Handle batteries with care to prevent physical damage that could lead to internal short circuits and subsequent fire resulting from thermal runaway.[13]
- *Proper Labelling:* Clearly label batteries to indicate their condition and hazards.
- *Secure Transportation:* Transport batteries in a secure, upright position to prevent movement and short circuits during transit. Use containers designed for battery transport.[10]

Storage Guidelines

- *Temperature Control:* Store batteries in a cool, dry place with stable temperatures. Avoid exposure to extreme heat or cold.
- *Fire Suppression:* Equip storage areas with appropriate fire suppression systems (e.g., Class D fire extinguishers).

---

[11] A Study on the Safety of Second-life Batteries in Battery Energy Storage Systems. GOV.UK

[12] IEC 62660-2:2018

[13] Safety Concerns with Li-ion. (n.d.). Battery University

- *Ventilation:* Ensure proper ventilation to prevent the accumulation of flammable gases.
- *Isolation:* Store batteries away from flammable materials and separate diverse types of batteries to prevent cross-reactions. [10]

Charging and Discharging

- *Controlled Environment:* It is crucial to conduct charging and discharging in a controlled setting with continuous monitoring to maintain safety and battery health.

- *Battery Management System (BMS):* Always connect the battery to a dependable BMS that oversees the charging and discharging cycles, preventing risks such as overcharging, excessive discharge, and overheating.

- *Avoid Deep Discharge:* Prevent batteries from experiencing deep discharge, as it can lead to irreversible damage and elevate the potential for thermal runaway, compromising safety and performance. [11]

Emergency Procedures

- *Spill Response:* In case of electrolyte leakage, follow appropriate spill response procedures, including neutralising the spill, using absorbent materials, and proper disposal. [11]
- *Fire Response:* If a battery catches fire, use a Class D fire extinguisher specifically designed for lithium battery fires. Do not use water as it can react with lithium to produce hazardous gases. [23]
- *Evacuation Plan:* Have an emergency evacuation plan in place for areas where batteries are handled or stored, and ensure all personnel are trained in emergency procedures.

Disposal and Recycling

- *Follow Regulations:* Dispose of or recycle batteries according to national regulations. [21]
- *Authorised Centres:* Use authorised battery recycling centres for safe and environmentally friendly disposal.
- *Documentation:* Keep records of battery disposal or recycling to ensure traceability and compliance with environmental regulations.

Training and Awareness

- *Periodic Training:* Provide periodic training and evaluation sessions to personnel on the safe handling, storage, and disposal of second-life batteries.
- *Hazard Communication:* Communicate the potential hazards associated with second-life batteries to all personnel involved in their handling. Have clear signage around all specialised work areas and assign a manager on duty to take responsibility for supervising ongoing works and workstations.

4.2 The risk matrix for battery management

The matrix in Table 7 prioritises key areas for battery safety and management by visualising the highest risks and guiding effective mitigation efforts. This matrix is also applicable to repurposing EV batteries for second-life applications.

Table 7 Battery safety and management risks

Risk	Likelihood	Impact	Risk Level	Mitigation Strategy
Thermal Runaway	2 (Possible)	5 (Severe)	10	Use thermal sensors, maintain adequate cooling, and implement thermal cutoff in the BMS.
Electrical Short Circuit	3 (Likely)	4 (Major)	12	Ensure proper insulation, regular inspection, and use of circuit breakers/fuses.
Overcharging/ Overdischarging	2 (Possible)	4 (Major)	8	Program BMS with strict voltage limits, use dependable chargers, and regular monitoring.
Physical Damage	3 (Likely)	3 (Moderate)	9	Use robust enclosures, proper handling procedures, and shock-absorbing materials.
Environmental Factors	2 (Possible)	3 (Moderate)	6	Store and operate batteries in controlled environments and use protective coatings.
BMS Failure	2 (Possible)	4 (Major)	8	Regular BMS testing, use of redundant BMS systems, and ensuring firmware is up to date.
Ageing and Degradation	4 (Likely)	2 (Minor)	8	Implement regular capacity testing and replace cells/modules when performance drops.

Risk Level Key:

- Low Risk (1-5): Acceptable; monitor and maintain.
- Moderate Risk (6-10): Requires action to reduce risk.
- High Risk (11-15): Immediate action required.
- Critical Risk (16-25): Urgent; requires immediate risk mitigation.

How to Use:

- Likelihood is rated on a scale of 1 to 5 (1 = Rare, 5 = Almost Certain).
- Impact is rated on a scale of 1 to 5 (1 = Insignificant, 5 = Catastrophic).
- Risk Level is calculated by multiplying Likelihood (L) by Impact (I).
- Mitigation Strategy provides actionable steps to reduce or eliminate the risk.

4.3 Logistics challenges associated with the collection, transportation, and processing of second-life batteries.

Addressing logistics challenges with second-life batteries is crucial for ensuring safety, regulatory compliance, and efficiency. Proper handling and transportation minimise risks and environmental impact, while effective management supports the circular economy by extending battery life cycles and reducing waste. Efficient logistics also help control costs and facilitate the integration of repurposed batteries into new applications, promoting sustainable practices and maximising their value. Logistics challenges associated with the collection, transportation, and processing of second-life batteries include:

Overcharging Risks - An overcharged lithium battery is more prone to overheating and catching fire compared to one charged to a lower capacity, such as 50% or 80%.[14] Overcharging can lead to thermal runaway, a condition where the battery uncontrollably increases in temperature, potentially causing fires or explosions during transit. Therefore, it is crucial to manage the state of charge (SOC) to mitigate these risks.

---

[14] Andersen, Safety Tips for Lithium-ion Battery Transport. Storemasta Blog

Shipping Regulations - Shipping fully charged lithium batteries is not recommended due to specific guidelines[15] that limits the SOC to 50% during transportation. These guidelines are tightly controlled by manufacturers to ensure safety. The reduced SOC minimises the risk of overheating and thermal runaway during transit.

Transportation Hazards - Several potential hazards are associated with transporting lithium-ion batteries, including:

- Short Circuits: Poor packaging or storage conditions can increase the risk of short circuits, leading to overheating and fires.
- Thermal Runaway: Physical damage, high temperatures, and overcharging can initiate thermal runaway, causing fires or explosions.
- Chemical Exposure: Damaged batteries can release hazardous chemicals that are corrosive and toxic.
- Incorrect Packaging and Labelling: Failure to follow regulations can result in mishandling and accidents during transit.

Storage Condition: Second-life batteries used in grid back-up and off-grid energy storage often need cooling systems to manage heat and ensure reliable performance. Proper storage conditions are essential to prevent further degradation and ensure safety. This requires specialized facilities equipped to control temperature, humidity, and ventilation, which help mitigate thermal stress and extend the lifespan of repurposed batteries. Maintaining these controlled environments ensures that second-life batteries operate efficiently and safely, supporting their use in energy storage solutions.

4.4 Efficient logistics and cost-effective solutions for managing the flow of second-life batteries.

Logistics solutions for managing the flow of second-life batteries involve several strategic steps, including optimising transportation, storage, and distribution of both batteries that have been retired from their first-life applications and collected for second-life manufacturers. The following are important logistical solutions to take into consideration:

Battery Assessment and Sorting

*Inspection and Testing***:** Protocols to assess the state of health (SoH) of incoming second-life batteries need to be established. This will help categorise batteries based on their suitability for various applications. *Sorting and Classification:* Create a system to categorise batteries by their remaining capacity, potential applications (e.g., stationary storage, low-power devices), and safety risks.

Efficient Transportation

Specialised Handling: This involves the use of transportation methods designed for hazardous materials, ensuring that batteries are protected from physical damage, extreme temperatures, and moisture during transit.[16]

---

[15] Lithium battery transport: all you need to know.

[16] Patel et al. Lithium-ion battery second life: pathways, challenges, and outlook

Route Optimization: Implementation of software solutions that optimise transportation routes to reduce time, costs, and carbon footprint, considering the distribution centres, collection points, and final destinations.[17]
Bulk Transport: Where possible, shipments to be consolidated to reduce the frequency of transport, lowering costs and environmental impact.

Strategic Storage Solutions

Centralised vs. Decentralised Storage: A decision to be made between centralised storage for easier management and control or decentralised storage for quicker deployment and reduced transportation needs.
Temperature-Controlled Warehousing: Batteries are to be stored in temperature-controlled environments to prolong their lifespan and maintain safety standards.
Inventory Management: Implementation of a robust inventory management system to track battery age, condition, and location, facilitating quick access and efficient distribution.

Distribution Planning

Demand Forecasting: Employment of predictive analytics to anticipate demand for second-life batteries in various markets, ensuring supply meets demand efficiently.
Regional Hubs: Establishment of regional distribution hubs to reduce delivery times and costs, particularly in areas with high demand or where logistics are challenging.
Partnerships: Formation of strategic partnerships with local distributors and service providers to enhance the reach and efficiency of your logistics network.

Digital Tracking and Monitoring

IoT Integration: Equipping batteries with IoT sensors for real-time tracking of their location, temperature, and state of charge during transportation and storage.
Blockchain for Traceability: Usage of blockchain technology to create a transparent, tamper-proof record of each battery's journey from initial use to second-life deployment, ensuring compliance and building trust with customers.[18]

Reverse Logistics

Collection Networks: Development of a network for collecting batteries at the end of their second-life use, ensuring they can be properly recycled or safely disposed of. (Gonzales et al., 2022)
Incentive Programs: Offer incentives for customers or partners to return used batteries, encouraging the recycling process and ensuring a steady supply of batteries for second-life applications.

Safety Considerations

Regulatory Compliance: Ensure that all logistics operations comply with local, national, and international regulations regarding the transport and storage of hazardous materials.

---

[17] Gonzales et al, Development of a Reverse Logistics Modelling for End-of-Life Lithium-Ion Batteries and Its Impact on Recycling Viability—A Case Study to Support End-of-Life Electric Vehicle Battery Strategy in Canada.
[18] Ruffino et al Blockchain review for battery supply chain monitoring and battery trading.

Emergency Response Planning: Develop and implement emergency response plans for potential incidents during transportation or storage, including spills, fires, or leaks. Training is required for emergency response teams to include police, paramedics and fire departments.

Sustainability Integration

Green Logistics: Incorporate electric or hybrid vehicles in your transportation fleet and prioritise eco-friendly packaging and storage solutions to reduce the carbon footprint.
Life Cycle Analysis: Continuously evaluate the environmental impact of logistics operations, aiming for improvements in energy efficiency and waste reduction.

Continuous Improvement

Data Analytics: Regularly analyse logistics data to identify bottlenecks, inefficiencies, or safety concerns, and implement continuous improvement strategies.
Feedback Loops: Establish feedback loops with customers and partners to refine logistics operations based on real-world experiences and needs.

4.5 Guidelines for handling, transporting, and disposing of second-life batteries.

Handling, transporting, and disposing of second-life batteries require adherence to safety and environmental standards. Safe handling involves using protective equipment and tools to manage battery weight and avoid hazardous exposure. Batteries should be stored in cool, dry places with fire safety measures to prevent leaks or thermal events. Transport must comply with regulations like UN 38.3, ensuring secure packing and labelling for safe transit.

For disposal, partnering with certified recycling facilities is essential to extract valuable materials and manage waste safely. Accurate documentation of battery history is important for traceability and compliance, supporting efficient lifecycle management. To reduce risks when transporting lithium-ion batteries, several precautions should be taken:

- State of Charge: Transport batteries at a specified SOC, recommended below 50%, to reduce the risk of thermal runaway and explosion from heat exposure.
- Battery Size and Quantity: Larger batteries or massive quantities of batteries may require temperature-controlled environments.
- Inspections: Inspect batteries before transport for signs of ageing, swelling, leaking, or damage.
- Avoid Water and Moisture: Store batteries in a dry, ventilated location to prevent water damage.
- Incompatibilities: Store lithium-ion batteries separately from other dangerous goods to avoid reactions, e.g. flammable materials, combustible gases, corrosive and conductive materials.
- Monitoring: Ensure continuous monitoring of storage conditions during transport to avoid exposure to extreme temperatures.
- Heat and Temperature Fluctuations: Keep batteries within a specific temperature range to prevent overheating.
- Impact Damage: Protect batteries from mechanical abuse to avoid thermal runaway caused by physical damage.

Figure 14 EV Batteries Preparation for Recycling

5. Economic Evaluation of Second Life Batteries

5.1 Market potential of different second-life applications.

Energy storage systems, particularly batteries, are essential for a clean energy transition. Global renewable energy capacity surged in 2023, driven by battery adoption in utility-scale projects, electric vehicles, and mini-grids. While Sub-Saharan Africa faces challenges in energy access, battery technology offers a promising solution. Battery costs have decreased significantly, making them more competitive. Repurposed batteries present a cost-effective alternative to new modules, promoting sustainability and circularity in battery usage.

5.1.1 Second-Life Battery Applications and Market Segmentation

Kenya is potentially a promising market for 2nd life batteries and their various applications, and this can be attributed to the extensive use of renewable energy and significant mini-grid and off-grid power infrastructure. Projects such as the Kenya Off Grid-Solar Access Project (KOSAP), a $150 million World Bank funded government project with targets to electrify 14 counties by constructing 120 mini grids and the sale of 250,000 stand-alone solar systems among other solar installation for schools, health facilities, administrative offices and community boreholes will be electrified using solar systems.[19] This expresses the national need for affordable battery storage systems, 2nd life batteries could potentially fill. [20] This is one of many off-grid renewable energy projects with numerous private developers also in the space.

Second-life battery packs offer diverse applications across various market segments in Kenya.

- Residential: Homeowners can benefit from energy storage solutions to optimise electricity consumption and reduce bills. This market segment requires an energy storage capacity of up to 150 kWh.
- Commercial: Charging stations and swap stations can leverage second-life batteries for reliable and cost-effective energy storage. This market segment requires an energy storage capacity of up to 500 kWh.
- Institutional: Schools, hospitals, and churches can improve energy efficiency and resilience through battery-based systems. This market segment requires an energy storage capacity of up to 500 kWh.
- Industrial: Grid support services and factory backup power can be enhanced with the integration of second-life batteries. This market segment requires an energy storage capacity of up to 10 MWh.

5.1.2 Current Repurposed Battery Landscape

Acele Africa (previously Aceleron)

A pioneering battery technology company based in Nairobi, Kenya that specialises in designing and manufacturing lithium-ion batteries tailored to electric mobility and renewable energy storage systems. They provide 3 offerings which include 1st life lithium-ion packs, repurposed 2nd life packs and cell

---

[19] https://documents1.worldbank.org/curated/ar/212451501293669530/pdf/Kenya-off-grid-PAD-07072017.pdf

[20] https://www.kosap-fm.or.ke/docs/solar-debt.pdf

testing and validation services. to date, they state they have recovered over 21 tons of battery waste and built over 1 MWh of battery packs. The company uses cylindrical cells to produce their battery packs.

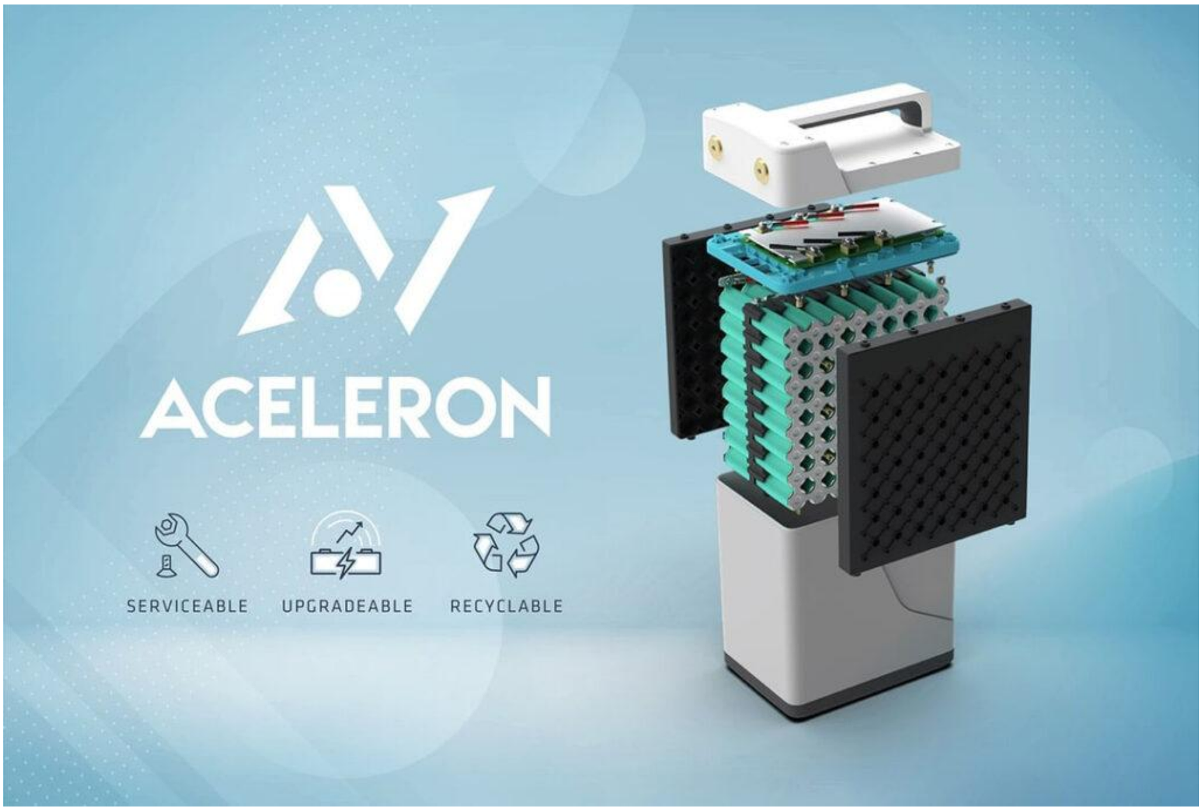


Figure 15 Acele Africa Battery Pack with proprietary compression technology.

Enviroserve Kenya Limited

A commercial social enterprise to deliver sustainable, environmentally friendly ways of managing electronic waste and contributing to a circular economy. Enviroserve's core business is waste management and recycling, it has embarked on 2nd life repurposing and cell testing to capture the battery waste component within the sector and improve the life cycle of EV and solar storage batteries. The company uses cylindrical cells from two-wheeler EV's as part of their repurposing materials. Enviroserve also perform cell testing and validation, after which it sells battery cells to other companies which include startups that are piloting 2nd life applications such as INNO-NEAT.

5.1.3 Financial Models for Battery Acquisition

To cater for diverse consumer preferences, various financial models for purchasing second-life batteries are available in Kenya. The most popular options include:

Table 8 Popular Financing Models in Kenya

	PROS	CONS
Outright purchase	● Full ownership: You have complete control over the asset. ● No monthly payments: Once purchased, there are no recurring costs. ● Potential for resale or asset appreciation	● High upfront cost: Requires significant capital outlay. ● Opportunity cost: Tied-up capital could be invested elsewhere. ● Responsibility for maintenance and repairs. ● The burden of battery disposal at the end of life is on the user. ● More likely to encourage improper disposal. ● Battery is more difficult to track at the end of life
Pay as you use	● Low upfront cost: No initial capital expenditure. ● Predictable expenses: Costs are based on usage. ● Flexibility: Can adjust usage based on needs ● The company maintains ownership of the battery and can easily track and properly dispose of or recycle it at the end of life	● Potential for higher long-term costs: Costs can accumulate over time. ● Limited control: You don't own the asset. ● Potential for price increases: Usage costs may fluctuate.
Lease to own	● Lower upfront cost than outright purchase. ● Opportunity to own the asset eventually. ● The user has ownership of the battery	● Higher overall cost than outright purchases due to interest charges. ● Ownership is not immediate. ● Potential penalties for early termination. ● Power consumption costs ● The burden of battery disposal at the end of life is on the user. ● More likely to encourage improper disposal. ● The battery is more difficult to track at the end of life

5.2 Component costs of reconditioning, refurbishing, repurposing, and reusing batteries.

The cost of repurposing an EV battery pack in Kenya is dependent on a number of factors, including the intended second-life application. While specific costs can fluctuate based on market conditions and technological advancements, a general breakdown of the factors affecting the cost of components includes battery acquisition, safety measures, battery testing and diagnostics, labour, energy storage system (ESS) integration costs and energy consumption.

Drivelectric, a Kenyan e-mobility company, acquired a fleet of 72 pre-owned Nissan Leaf electric vehicles. After successfully rehabilitating the ageing fleet, the company identified a subset of vehicles with diminished State of Health (SOH) batteries, unsuitable for continued traction applications. To maximise the value of these retired batteries, a research project was conducted to repurpose them into stationary energy storage solutions for both residential, commercial and institutional settings.

Figure 16 pre-owned electric vehicles acquired by Drivelectric

The following case studies demonstrate the various applications of repurposed EV batteries in second-life applications:

Case Study 1: Institutional Solution

Studies show that most retired Nissan Leaf Gen 1 battery packs have good consistency and balance, allowing them to be repurposed as whole packs without the need for disassembly and reassembly into modules. This significantly reduces the repurposing cost compared to other EV batteries that may require more extensive refurbishment, which requires disassembly to module or cell level. Within the Kenyan context, Drivelectric used batteries from their ageing fleet to create an institutional battery pack. The battery was extracted from a 2014 Nissan Leaf EV with an original battery capacity of 24 kWh that had degraded over time to a state of health of 34%. This battery was integrated into a robust structure and coupled with an inverter. The result was a 7.77 kWh battery pack that was priced at Ksh 185,000 exclusive of installation and transportation.

Case Study 2: Residential Solution

Drivelectric developed a prototype residential battery pack by disassembling a Nissan Leaf EV battery pack, rigorously testing individual cells, reconfiguring them into new packs, and enclosing them in a protective casing. This led to a repurposed EV battery of a 2.4 kWh battery pack developed at a cost of Ksh 65,900, meant for residential applications. A breakdown of the costs is shown in Table 9. This is exclusive of transport and installation.

Table 9 Cost breakdown for a 2.4 kWh LFP repurposed battery for the residential use case

Material	Costs
Cells	Ksh 14,000
BMS	Ksh 10,500
Casing	Ksh 16,500
Labelling	Ksh 400
Cell & Battery Testing	Ksh 14,000
Labour	Ksh 10,500
Final Cost	**Ksh 65,900**
Battery Cost/kWh	**Ksh 27,460 or USD 211**

An observation arises from the cost comparisons of the piloted systems per unit of energy. The smaller residential system that requires disassembly to a modular level, compared to the larger capacity institution pack, ranged from Ksh. 27458/kWh to Ksh. 23810/kWh. The variance in price is Ksh. 3648/kWh. As these are pilot studies, economies of scale are yet to be fully realised, but this already shows a 13% price reduction when creating solutions that use the original pack in its original form factor.

5.3 Longevity of second-life batteries under different use cases.

Second-life EV batteries can have a wide range of lifespans depending on their specific use case, with estimates ranging from 4.7 to 30 years. The longevity is influenced by factors such as the battery's degradation level at the end of its first life, material quality, the duty cycle and operating conditions in the second-life application, and the battery's configuration and management system.

In general, second-life applications with lower power and lower depth of discharge requirements, such as EV fast charging support, tend to have longer lifespans compared to those with more frequent and higher depth of discharge scenarios. For example, one study simulating different applications found that second-life batteries can last up to 30 years when used for fast EV charging support, but only 4.7 to 7.5 years when used in grid regulation and transmission deferral applications.[21]

The remaining useful life (RUL) of second-life batteries is a critical factor in determining their economic viability. Accurate estimation of the RUL is challenging due to uncertainties around the battery's degradation history from its first life and the operating conditions in the second-life application. Developing better models to predict battery ageing and the state of health in second-life use is an active area of research.

Factors like elevated temperature, fast charging, DC charging, and battery age can accelerate the loss of active material, loss of lithium inventory, and conductivity loss in lithium-ion batteries. DC charging, especially at high rates, can lead to increased lithium plating and subsequent SEI growth, resulting in a higher loss of lithium inventory compared to AC charging. The higher current densities associated with DC charging appear to exacerbate lithium inventory loss mechanisms.

The duty cycles frequently stated by most of the static storage lithium-ion battery manufacturers range from 3500 to 7000 duty cycles. If a battery of this nature goes through one duty cycle each day, the battery will have an expected life cycle of between 9 years to 16.4 years.

---

[21] Casals et al, Reused second life batteries for aggregated demand response services.

The repurposed EV batteries also boast a variation in duty cycles, their performance is dependent on the parameters listed in section 2.3. The expected cycles range from 1400-2000 cycles, which would give 3.8-5.5 years of use, if we match the sage to that of the static storage batteries.

5.4 Market equivalents/ Competitive landscape:

Competition is stiff for storage solutions, considering technology is constantly improving and material costs are decreasing. Tables 9 highlight the competitive landscape for the battery packs. Considering economies of scale, the cost of the repurposed battery pack is likely to be lower.

Table 10 compares low-voltage batteries to the GreenCell battery developed by Knights Energy for residential use. Table 9 focuses on brand, battery chemistry and cost per unit of energy. The table provides a straightforward comparison of prices that would be affected by preferences on brand selection. When comparing locally available batteries from leading manufacturers, the most common options for residential applications typically range from 4.8 kWh to 5.2 kWh, therefore, two GreenCells would be required to match the energy storage capacity of the static batteries. The table below draws comparisons on the cost of new stationary application batteries versus the second-life repurposed batteries from various sources. It is apparent that the overall cost per kWh is lower for the repurposed battery however, there are factors which come into play, including duty cycles, capacity fade and other metrics which need to be explored further to understand the full lifecycle cost of the second-life battery presented. The green cell shows a 27% to 48% price reduction per kWh when compared to the other stationary batteries. The GreenCell and INNO NEAT's pilot boast similar values of USD 211 and USD 215, respectively, which gives more confidence in the pricing values. As the repurposed batteries in question stem from pilot studies, economies of scale are yet to be felt, which can potentially improve the cost implications of using 2nd life EV batteries.

Table 10 Characteristics of common low-voltage batteries in the Kenyan market

Battery Type	Key Specifications	Cost in Ksh	Cost/kWh (Ksh)	Cost/kWh (USD)
BYD LV Flex Lite 5 kWh	Cobalt-Free Lithium Iron Phosphate (LFP)	290,000	52,727	**406**
JINKO 4.8 kWh	Lithium Iron Phosphate (LFP)	240,000	50,000	**385**
FELICITY 5 kWh	Lithium Iron Phosphate (LFP)	187,000	37,400	**288**
GW-A-ENERTEC GL48100 5 kWh	Lithium Iron Phosphate (LFP)	209,000	41,800	**322**
GROWATT AXE 5 kWh	Lithium Iron Phosphate (LFP)	200,000	40,000	**308**
Weco 5.3 kWh	Lithium Iron Phosphate (LFP)	280,000	52,830	**406**
2nd Life Repurposed Battery				
Greencell V1 2.4 kWh	Lithium Manganese Oxide (NMO)	69,500	27,460	**211**
INNO NEAT 1.3 kWh	Lithium Ion	36,335	27,950	**215**

5.5 Economic viability of exporting battery materials for recycling.

To evaluate the feasibility of exporting recyclable materials from End-of-Life (EOL) EV batteries, both market price and export costs are considered to calculate the net export value. The market price was derived using a reducing balance depreciation method, with initial costs informed by Drivelectric's data on commercial battery packs (Ksh 65,900 or USD 535). The salvage value was based on the market price for recycled EV batteries, noted at $15 per kWh for LFP batteries. The EOL battery was assumed to retain a capacity of 1 kWh or less, with lifespan estimates referencing EV batteries in residential PV applications.

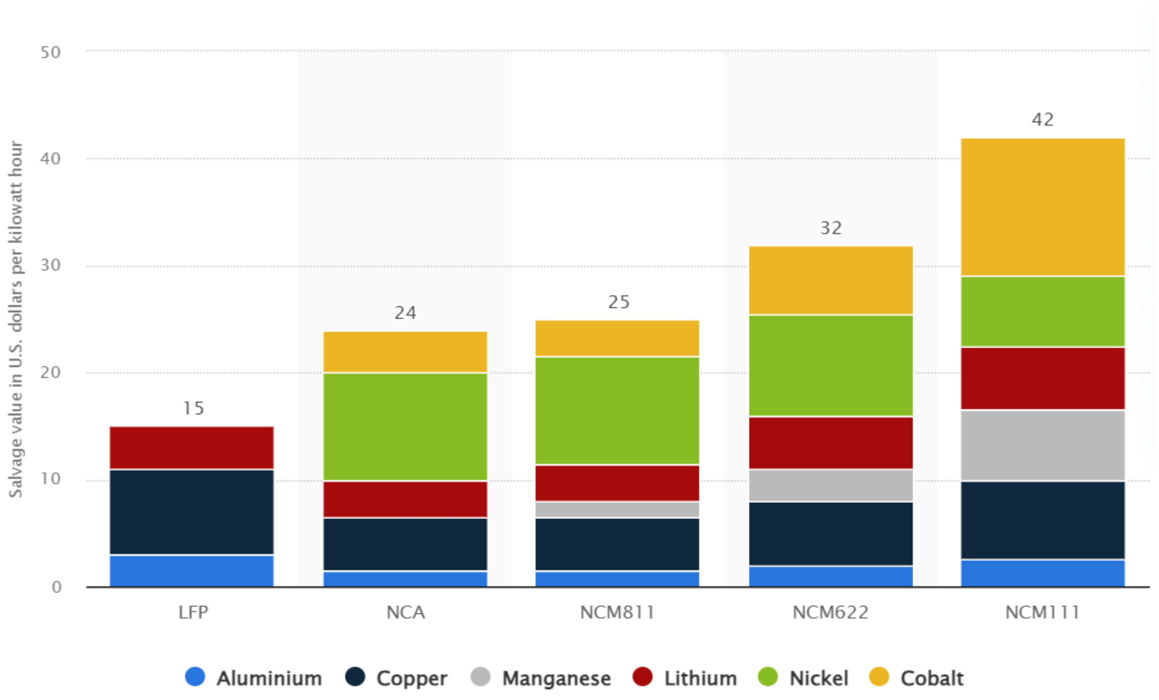


Figure 17 Value of recycled electric vehicle (EV) batteries in 2020, by cathode chemistry (in Statista. Retrieved 5th August 2024 from [22])

After five years of service in residential PV storage, an EV battery at EOL is estimated to have a market value of Ksh 1663 (or USD 13). Exporting this battery involves exportation costs at 16% VAT, a 25% export duty, and 0% excise duty. Considering these expenses, the net export price for the EV battery scrap is calculated to be Ksh 2344 (or USD 18) per battery.

The option of constructing a recycling hub can be considered, however, this may be a long-term solution to waste management given the costs required. A battery recycling engineering hub cost study was published in the Financial Times, conducted by Neometals Limited, an Australian-based battery materials producer, to assess the cost of setting up such a plant with a throughput capacity of 50 tonnes per day. The cost accuracy stated is +/-25%, which shows a huge variation in potential costs.[23]

Table 11 Costing estimate of battery recycling engineering hub- estimates from Neometals Ltd

Plant Type	Shredding Spoke Facility (to produce black mass)	Refining Hub (to process black mass)
Capital costs	USD 102.5 million	USD 303 million
Annual Operating Cost	USD 30 million	USD 61 million

The high capital cost and required throughput are a challenge for Kenya, which has yet to grow its battery capacity. Consolidation of regional waste may be the key to unlocking viability and capital gains in critical mineral recovery.

---

[22] Statista. Value of recycled electric vehicle (EV) batteries in 2020, by cathode chemistry https://www.statista.com/statistics/1246828/value-of-recycled-ev-batteries-by-battery-type/

[23] Financial Times. Battery Recycling 'Hub' Engineering Cost Study

5.6 Economic benefits of second-life applications

The economic viability of the second life application of EV batteries depends on different key factors such as the technical performance at the end of the first-life application, and the cost of repurposing depending on the chemistry, size and intended second-life application of the battery. Several pathways exist at the end of the first life application that could be repair or reconditioning for continued use in the first life application, repurposing for second-life applications, or recycling to recover valuable materials. Disposal is often a last resort, typically occurring in regions lacking the necessary battery manufacturing or recycling infrastructure or if the battery is damaged. Repurposing is highly valuable in markets requiring stationary energy storage, with key applications in grid reliability, investment deferral, and renewable power storage. By 2025, second-life batteries could be 30-70% cheaper than new ones for these uses.[24]

The economic benefits of second-life battery applications are evident in the increased domestic value creation. Companies can leverage local and recovered resources, such as metal structures, plastics, and other materials, to reassemble batteries for second-life use, as demonstrated by the "GreenCell" battery pack. This reduces the need to import new batteries or purchase additional raw materials, thereby maximising the value of each battery over a longer period. By extending the lifespan of batteries, the recycling process is postponed until necessary. This is particularly advantageous in countries like Kenya, where recycling infrastructure for lithium-ion batteries is lacking, as it reduces the need for costly battery exports to regions with recycling capabilities.

Kenya's second-hand vehicle market, expected to expand to include electric vehicles (EVs), will soon face a rising demand for battery repair and repurposing. As imported EVs approach the end of their first-life applications, there will be an increasing need to extend battery life spans through repairs and repurposing, reducing the e-waste generated by EV batteries.

Figure 18 presents the increasing supply of second-life EV batteries from 2020 to 2030 globally. McKinsey & Company reported that globally, this supply could exceed 200 gigawatt-hours per year for stationary applications by 2030, surpassing the demand for lithium-ion storage systems[25]. In this same period, this market is projected to exceed $30 billion in global value.

---

[24] McKinsey & Company. Electric vehicles, second life batteries, and their effect on the power sector.

[25] McKinsey & Company. Second-life EV batteries: The newest value pool in energy storage. April 2019

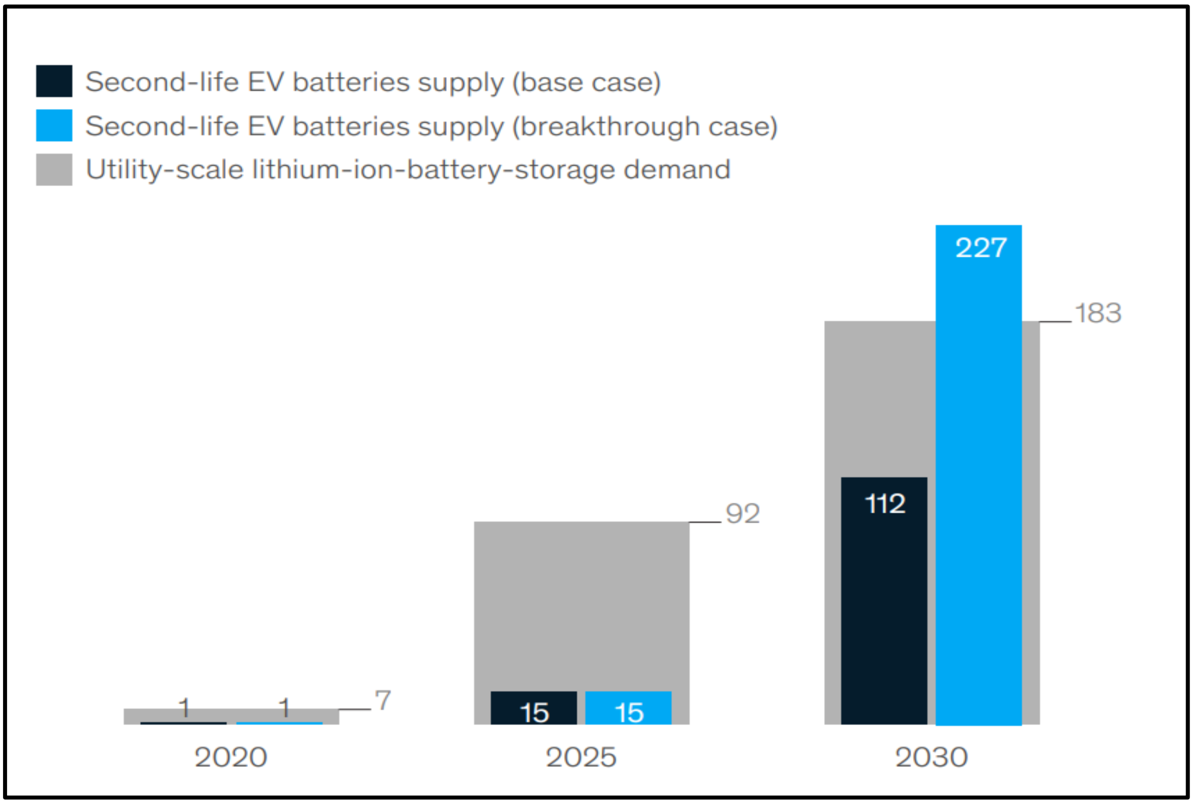


Figure 18 Second-life lithium-ion battery supply could surpass 200 gigawatt-hours per year by 2030 (Source: McKinsey & Company)

As the deployment of variable renewable energy sources like wind and solar continues to grow, maintaining grid stability becomes increasingly important. Battery Energy Storage Systems (BESS) utilising repurposed EV batteries present a solution by offering energy storage, grid stability support, and ancillary services, as well as deferring infrastructure investments in static storage. These systems not only support the integration of renewable energy but also foster economic opportunities while promoting sustainability and circularity in the energy and transport sector.

However, several challenges must be overcome to fully realise the potential of second-life applications. These include:

- The diminishing cost differential between new and repurposed batteries, as the rapid decline in new battery costs is outpacing the reduction in re-manufacturing costs. Battery prices have fallen by 90% in less than 15 years, to under $140/kWh in 2023, thanks to R&D, economies of scale, and technological advancements.[26]
- The variation of battery chemistries and configurations results in variable performance characteristics, complexity in sorting and testing[27]difficulty in interoperability and complexity in the configuration of repurposed batteries.
- A lack of dedicated standards and regulations for EV battery repurposing to ensure safety and performance.

---

[26] IEA, Batteries and Secure Energy Transitions

[27] Azizighalehsari S, Venugopal P, Pratap Singh D, Batista Soeiro T, Rietveld G. Empowering Electric Vehicles Batteries: A Comprehensive Look at the Application and Challenges of Second-Life Batteries. *Batteries*. 2024; 10(5):161. https://doi.org/10.3390/batteries10050161

- Insufficient collection centres and business models that incentivise EV owners to return decommissioned batteries for repurposing.
- Low volumes of available EV batteries for second-life applications, particularly in developing countries where the need for BESS is greater.
- The different battery pack designs and chemistries available in many sizes and form factors, such as cylindrical, prismatic, and pouch, make the process complicated, and in most cases, it informs the most viable business model based on the intended application.

Accurately modelling the health of EV battery packs during their initial use could improve the economic feasibility of reuse. For instance, the National Renewable Energy Laboratory predicted that with readily available vehicle diagnostic data, repurposing costs could drop to as low as $20 per kilowatt-hour (kWh).[28] Other studies have found that second-life battery systems could be sold for between $60 and $175 per kWh, offering competitive pricing compared to new batteries. However, the economic return post-repurposing was estimated to be about $35 per kWh by 2030, potentially making it less attractive for bulk sales and large-scale installations.

---

[28] NREL. J. Neubauer, K. Smith, E. Wood, and A. Pesaran. Identifying and Overcoming Critical Barriers to Widespread Second Use of PEV Batteries

6. Policy and regulatory framework

6.1 Existing policy and regulatory framework in Kenya related to second-life applications of traction batteries.

The policy and regulatory framework should ensure that only high-quality, safe, and reliable batteries both new and second-hand, are allowed on the Kenyan market. This should address the entire battery lifecycle, from collection and repair or reconditioning to repurposing and recycling at the end of their life.

The transition to electric mobility in Kenya is rapidly progressing, particularly in the two-wheeler sector, with other segments like e-bicycles, e-tuk-tuks, e-buses, and e-cars also emerging. This shift is vital for achieving sustainable, emission-free transport solutions. Kenya's landscape includes both the importation of second-hand vehicles and the local assembly of new electric vehicles, such as e-motorbikes by ROAM and e-buses by BasiGo. This growth brings an influx of second-life EV batteries and new batteries assembled for first use, making battery lifecycle management crucial for sustainability and e-waste management. Kenya has established a framework of policies aimed at managing waste, including partnerships with the International Electrotechnical Commission Global Impact Fund (IEC-GIF), which aims to address the challenge of battery e-waste. Alongside this, other crucial policies and measures that have been proposed for effective waste management such as summarised in Table 12 below.

Table 12 Policies and measures addressing waste management.

Policy Document	Year
The 1989 Basel Convention International Treaty on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.	1989
Kenya Constitution	2010
NEMA E-waste Guidelines	2010
The Environment Management and Coordination Act (EMCA)	2015
NEMA National Solid Waste Management Strategy	2015
UNEP & International Solid Waste Association The Global E-waste Outlook	2017
The Draft National Guidelines for Extended Producer Responsibility (EPR)	2018
UNEP African Waste Outlook	2018
National E-Waste Strategy	2019
MoEF National Sustainable Waste Management Bill	2021
Ministry of Environment and Forestry (MoEF) National Sustainable Waste Management Policy	2021
The Sustainable Waste Management Act,	2022

In addition, there are 35 e-mobility standards that KEBS has currently developed. The standards related to battery packs as stated hereunder:

- KS ISO 12405-4:2018: Test specifications for lithium-ion traction battery packs and systems.
- KS ISO 18300:2016: Test specifications for lithium-ion battery systems combined with lead-acid batteries or capacitors.

Other standards in the KS ISO 21782 series also include specific tests for battery packs or components, and KS ISO 6469-1 covering safety requirements for rechargeable energy storage systems (RESS), which include battery packs. Standards focusing on energy consumption and range, such as KS ISO 8714, implicitly involve testing battery performance.

6.2 Regulatory Recommendations.

To effectively address the growing challenges and opportunities associated with EV battery waste, Kenya should consider implementing a comprehensive set of policy recommendations. The recommendations aim to create a supportive environment for sustainable battery management, promote innovation, and ensure that the benefits of EV adoption are maximised while minimising environmental impacts.

Enhancement of Data Collection and Management

- Comprehensive Battery Passport: Implement a mandatory battery passport system, capturing detailed information about each battery, including SOH, manufacturing date, and usage history. This data should be collected by importers through PVOC and insurance companies during annual inspections.
- Logging data at importation: KEBS to request importers to log the SOH through PVOC (Pre-Export Verification of Conformity). This data should be sent to NTSA and added to the battery passport.
- Logging data during annual inspection checks: Insurance companies are to log the current SOH during annual inspection checks so that battery degradation can be monitored. This will enable stakeholders to predict battery degradation patterns and project the stock of second-life batteries.
- Centralised Data Repository: Establish a secure, centralised data repository managed by NTSA to store and analyse battery data. The information should be shareable between different agencies and supply chain actors while retaining anonymity. This will enable accurate prediction of battery degradation patterns and available second-life battery stock.
- Data Sharing Protocols: Develop clear guidelines for data sharing among relevant stakeholders, ensuring data privacy and security while facilitating research and development.

Standardised Testing and Certification

- Develop National Standards: Create specific Kenyan standards for testing and certifying second-life batteries, building upon existing international standards (IEC 61427-1)
- Expand existing standards: Adapt standards like KS ISO 12405-4 and KS ISO 18300 to specifically address second-life batteries. Factors to be considered should include (but not be limited to):
    - State of Health
    - Remaining Useful Life
    - Capacity Retention
    - Thermal Management
    - Cycle Life
    - Mechanical Integrity
    - Compliance with regulations for repurposing, recycling, and disposal
    - Application Suitability

- Performance Benchmarks: Define clear performance benchmarks for different second-life battery applications to guide product development and consumer confidence. Include guidelines based on their intended application. Performance metrics include:
    - Energy Density
    - Cycle Life
    - Efficiency
    - Energy Storage Capacity
    - Power Output
- Rigorous Safety Assessments: Mandate comprehensive safety assessments for all second-life batteries, including:
    - Thermal Runaway Testing
    - Short-Circuit Protection
    - Overcharge/Discharge Prevention
    - Temperature Monitoring
    - Mechanical Integrity
    - Physical Damage
    - Environmental Factors
    - BMS Failures
- Advanced Battery Management Systems (BMS): Require advanced BMS for second-life batteries to monitor cell health, balance, and temperature, mitigating safety risks.
- Safe Transportation and Handling: Establish guidelines for the transportation and handling of second-life batteries to minimise accidents and environmental hazards. Ensure users consider the following:
    - Transport batteries at a lower State of Charge to reduce the risk of thermal runaway and explosion from heat exposure.
    - Provision of temperature-controlled environments for larger batteries.
    - Inspect batteries before transport for signs of ageing, swelling, leaking, or damage.
    - Store batteries in a dry, ventilated location to prevent water damage.
    - Keep batteries within a specific temperature range to prevent overheating.
    - Ensure continuous monitoring of storage conditions during transport to avoid exposure to extreme temperatures.
    - Protect batteries from mechanical abuse to avoid thermal runaway caused by physical damage.
- Degradation assessment: Develop methods to accurately assess the degradation state of second-life batteries to determine their suitability for specific applications. This includes developing models to predict the remaining useful life (RUI) of a battery.

Recycling and Disposal

- End-of-life management: NEMA should review the existing guidelines for the recycling and disposal of second-life batteries when they reach the end of their life.
- Material recovery: Promote the recovery of valuable materials from spent batteries. Create incentives for the creation of battery recycling centres.

Consumer Protection

- Clear labelling: Mandate clear labelling of second-life battery products, including information about the battery's history, capacity, and performance limitations.

- Warranty requirements: Implement warranty requirements for second-life battery products to protect consumers.

Regulation Implementation

- Develop EV Circularity Roadmap: Create a roadmap with phased implementation strategies that identify research priorities and practical implementation strategies for data collection, standardisation, and other necessary measures. This includes setting clear timelines for achieving specific goals, such as establishing a national database for EV battery information or implementing a battery passport.
- Public-Private Partnerships: Encourage public-private partnerships to share the financial burden and leverage expertise from both sectors. This can be done through tenders or capacity building.
- Continuous Evaluation and Adaptation: Regularly evaluate the effectiveness of the policies and make necessary adjustments based on emerging trends and challenges. These accountability metrics can be added to the EV circularity roadmap.

In 2023, the EU's directives on batteries and waste management were updated in line with the circular economy action plan and industrial strategy. The revised rules cover the entire life cycle of batteries, from design and use to recycling, ensuring batteries can be repurposed, remanufactured, or recycled. They also introduced a new category for "light means of transport" batteries, like those for e-bikes and e-scooters. Manufacturers are required to conduct due diligence for socially and environmentally responsible raw material sourcing, and stricter recycling targets have been set, specifying collection and recovery percentages.

6.3 Recommendations for implementing battery passports using EU regulatory experience.

In the European Union, initiatives are in motion to implement Battery Passports. By 2025, EU battery manufacturers will be required to validate their carbon footprint through independent third-party verification, with data accessible online. Starting in 2027, all EVs, light transport, and industrial batteries greater than 2 kWh sold in the EU must have unique battery passports.[29] By 2028, batteries will undergo a comprehensive sustainability assessment to meet carbon footprint limits, including documentation on the percentage of recycled materials like cobalt, lead, lithium, and nickel used in the batteries. Figure 19 shows the roadmap the EU is undertaking to make batteries sustainable throughout their entire life cycle.

---

[29] Stretton, C. (2023, December 11). EU battery passport regulation requirements. Circularise

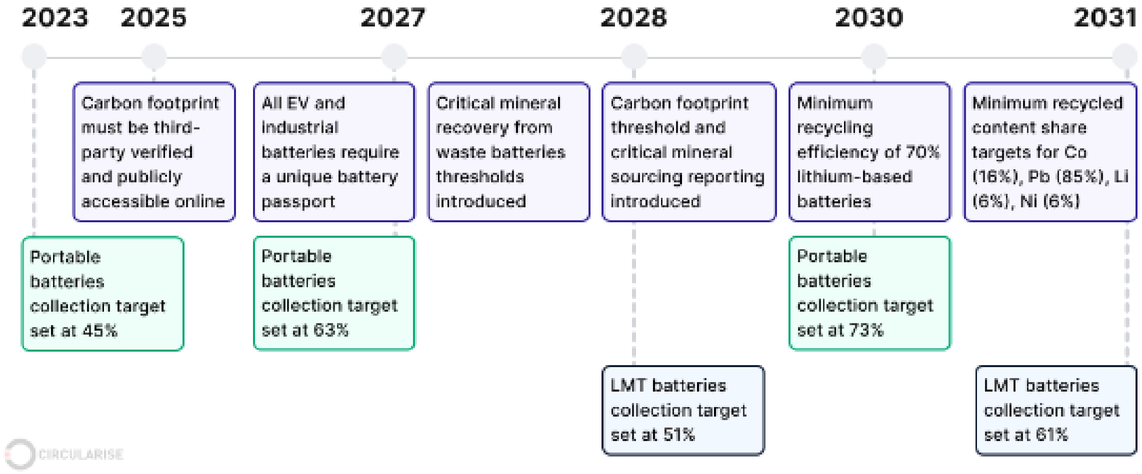


Figure 19 EU Key dates for other Battery Regulation requirements[30]

Based on lessons from the European Union, the following recommendations for developing and implementing battery passports are worth considering.

6.3.1 Policy Development

i. Developing the Battery Regulation:
  - Provide guidelines for managing all battery types across different use cases including sectors like EVs and industrial stationary applications (e.g., power systems).
  - Establish measures for EV battery repurposing and creating suitable market use cases.
  - Consider carbon footprint reporting that will look at sourcing of the raw materials, manufacturing of the battery, distribution, and end-of-life management of the battery. This reporting is important to assess sustainability.

ii. Standardisation:
  - Standardisation becomes key in both the battery (product allowed in the market) and data spaces. This provides a standardised technical infrastructure based on a governance framework, ensuring efficient and secure data sharing and transactions within an ecosystem.
  - In the context of battery passports across sectors, standardised data sharing is crucial as it impacts business models, protection of intellectual property, trade secrets, and operational processes. Therefore, businesses must simultaneously develop their business, organisational, and technological capabilities to align with standardised data-sharing practices.

6.3.2 Infrastructure Development

i. Data Centre Infrastructure:
  - To ensure the successful implementation of a battery passport system, essential technical standards must be integrated, including:
    - IT Infrastructure: Robust systems for data handling and storage.
    - Software Functions: Specialised tools for tracking and managing battery data.

---

[30] Circularise

    - Management Systems: Efficient processes for overseeing the lifecycle of batteries.
    - Governance Systems: Policies and procedures to ensure compliance and security.
  - These components form the foundation for achieving safe, secure, and cost-effective battery passport operations.

ii. Interoperability:
  - To ensure the secure and reliable exchange of potentially sensitive data among various stakeholders (including consumers, business partners, and authorities) it's crucial to integrate existing market technologies seamlessly.
  - The battery passport system should remain adaptable and open to accommodate global advancements while safeguarding data integrity. This approach fosters collaboration across sectors, supports future developments, and promotes the efficient operation of the battery passport framework.

6.3.3 Policy Deployment

i. Manufacturer and Stakeholder Collaborations:
  - Promote sustainability and Extended Producer Responsibility (EPR). Section 13 of the Sustainable Waste Management Act requires every producer to bear mandatory Extended Producer Responsibility (EPR) to reduce pollution and environmental impacts arising from products introduced into the Kenyan market and waste arising therefrom. Section 13(2) states that each producer shall fulfil their EPR obligations either individually or collectively in a compliance scheme.
  - The batteries and the battery passport must be incorporated under the EPR regulation and enforced.
  - Building capacity to support end-of-life management i.e. recycling capabilities working with manufacturers and stakeholders in the end-of-life management such as repurposing.

ii. Integration with Other Policies:

  - Align with Environmental Management and Co-Ordination Act, 1999 Amended 2015 and The Waste Management Regulations, 2006 for environmental impact, recycling targets, and hazardous substances management.

iii. Implementation:

  - The development of detailed road maps is essential for the phased implementation of the battery passport system. These roadmaps will establish clear milestones and objectives, enabling coordinated efforts among stakeholders and ensuring that the system's rollout is both strategic and effective with specific timelines.
  - This approach will help align the various phases of implementation, allowing for adjustments as necessary and ensuring that all parties involved are working towards common goals with a clear understanding of the timeline and expectations.

To facilitate this and drawing from the EU Battery Directive, Kenya could benefit from clear policy development, robust infrastructure, standardisation, and effective stakeholder collaboration, ensuring the success of the battery passport system.

6.4 Feasibility of implementing battery passports in Kenya.

To address these challenges, the Global Battery Alliance (GBA) conceptualised the Battery Passport as a framework to increase transparency across the battery value chain. GBA defines the Battery Passport as a global reporting framework governing rules around the measurement, auditing, and reporting of ESG parameters across the battery value chain.

Implementing a battery passport in Kenya requires a multi-stakeholder approach, involving collaboration between the public, private sector, policymakers, regulators, ICT and data specialists, and international partners. This effort will demand the integration of various key considerations such as:

- Regulatory Framework: Establishing policies aligned with global standards, ensuring compliance, and fostering cooperation among government and industry stakeholders. The regulation should also focus on the aspect of repurposing, where the battery begins second-life applications.
- Technical Infrastructure: Developing a robust digital system to track battery data throughout its lifecycle, including databases to collate, exchange, store and report data.
- Standardisation and Interoperability: Establishing a standardised framework for battery passports will ensure consistency in data collection and reporting across different stakeholders, making it easier to track and compare battery performance.
- Economic Feasibility: Assessing the economic viability based on EV adoption in Kenya and forecasting battery volumes for both local use and export for recycling.
- Stakeholder Collaboration: Encouraging collaboration among government agencies, EV manufacturers, assemblers, battery repurposing and recycling, including implementing Extended Producer Responsibility (EPR).

- Public Awareness and Education: Raising awareness among stakeholders and the public about the importance of battery passports for effective implementation and widespread acceptance.

Implementing a battery passport system for packs or modules entering Kenya is feasible, but faces certain challenges. The system would need to standardise and digitise essential data, such as state of health (SoH), manufacturing details, and service history, ensuring traceability throughout the battery's life cycle. However, a significant challenge is that batteries typically arrive as complete packs, with a need for detailed tracking required when disassembled into modules or cells to build new repurposed packs. This means it is important to localise the digitised systems to capture the data when disassembly of the battery packs takes place. Examples like Aceleron Africa's cell passport illustrate potential solutions, but adapting the system to various pack designs, like pouch cells requiring specialised handling, adds complexity. Ensuring compliance and integrating with regulatory frameworks would require collaboration among manufacturers, importers, and regulators.

6.5 Benefits and challenges of implementing battery passports.

The benefits of implementing a battery passport bring several positive developments that are focused on unlocking the potential opportunities across battery supply chains. Some of the major benefits are:

- Sustainability: Encourages the adoption of eco-friendly practices by improving battery lifecycle management, supporting a circular economy, and reducing environmental impact.
- Quality Assurance: Ensures higher standards in battery manufacturing and assembly, leading to longer-lasting, safer batteries. working with organisations that demonstrate quality and safe batteries for the local market.
- Data Transparency: Provides detailed data on battery performance, usage, and environmental impact, aiding informed decision-making in the end-of-life management of the battery.

- Standards and Regulatory Compliance: This ensures the alignment with global standards, enhancing Kenya's competitiveness in the global market, taking advantage of the opportunities in the sector.
- Economic Growth: Opens avenues for businesses to monetise sustainable practices and create new economic opportunities in battery waste management for recycling and repurposing.
- Carbon Footprint: Access to the carbon footprint information can help increase consumers' awareness of the environmental impacts of batteries, which is important for eco-conscious decisions by consumers promoting sustainable practices.

Several challenges have been identified when it comes to the implementation of battery passports. These challenges include:

- Standardisation: Aligning Kenya's battery industry with international standards for battery passports, particularly in electric vehicle assembly, may necessitate significant regulatory adjustments and industry collaboration.
- Data Reliability: Ensuring accurate and valid data collection is challenging, especially where processes are underdeveloped.
- Technical Infrastructure: Developing a robust centralised digital system for tracking battery data is complex and resource-intensive, particularly in the informal sectors where a lot of the breakdown of batteries is likely to happen, potentially limiting adoption by smaller companies.
- Confidentiality Concerns: Companies and stakeholders may be reluctant to share sensitive data, leading to potential data silos.
- Interoperability: The lack of universal standards for seamless data exchange among battery supply chain actors can hinder effective implementation.

The feasibility of implementing battery passports in Kenya is crucial as the country transitions to electric mobility, especially with the rise of electric vehicles (EVs) like e-motorbikes and e-buses. A battery passport system would enhance transparency and sustainability in managing the lifecycle of both new and second-life EV batteries, addressing challenges such as e-waste and environmental impact. Key considerations include establishing a regulatory framework aligned with global standards, developing technical infrastructure for data tracking, ensuring standardisation and interoperability, assessing economic viability, and fostering stakeholder collaboration. Integrating these elements will promote sustainable battery management and support Kenya's growing EV sector.

Policy Development

1. **Battery Regulation**:
    - Develop comprehensive guidelines for managing all battery types across various sectors, including electric vehicles (EVs) and industrial applications.
    - Establish measures for EV battery repurposing and create suitable market use cases.
    - Implement carbon footprint reporting that covers the sourcing of raw materials, manufacturing, distribution, and end-of-life management.
2. **Standardisation**:
    - Standardise both battery products and data sharing to ensure efficient and secure transactions within the ecosystem.
    - Align business, organisational, and technological capabilities with standardised data-sharing practices.

Infrastructure Development

1. **Data Centre Infrastructure**:
    - Integrate essential technical standards, including robust IT infrastructure, specialised software functions, efficient management systems, and governance policies.
    - Ensure these components form the foundation for safe, secure, and cost-effective battery passport operations.

2. **Interoperability**:
    - Ensure secure and reliable data exchange among stakeholders by integrating existing market technologies.
    - Maintain adaptability to global advancements while safeguarding data integrity, fostering collaboration across sectors.

Policy Deployment

1. **Manufacturer and Stakeholder Collaborations**:
    - Promote sustainability and Extended Producer Responsibility (EPR) under relevant regulations.
    - Build capacity for end-of-life management, including recycling and repurposing, in collaboration with manufacturers and stakeholders.
2. **Integration with Other Policies**:
    - Align with environmental and waste management regulations for comprehensive sustainability.
3. **Implementation**:
    - Develop detailed roadmaps for phased implementation, establishing clear milestones and objectives.
    - Ensure coordinated efforts among stakeholders with specific timelines and expectations.

Feasibility of Implementing Battery Passports in Kenya

- **Regulatory Framework**: Establish policies aligned with global standards, focusing on battery repurposing.
- **Technical Infrastructure**: Develop robust digital systems for tracking battery data throughout its lifecycle.
- **Standardisation and Interoperability**: Ensure consistent data collection and reporting across stakeholders.
- **Economic Feasibility**: Assess economic viability based on EV adoption and forecast battery volumes for local use and export.
- **Stakeholder Collaboration**: Encourage collaboration among government agencies, EV manufacturers, assemblers, and recycling entities.
- **Public Awareness and Education**: Raise awareness about the importance of battery passports for effective implementation and acceptance.

Benefits and Challenges

Benefits:

- Promotes sustainability and eco-friendly practices.
- Ensures quality assurance and data transparency.
- Aligns with global standards, enhancing competitiveness.
- Opens economic opportunities in battery waste management.
- Increases consumer awareness of environmental impacts.

Challenges:

- Aligning with international standards may require significant regulatory adjustments.
- Ensuring accurate data collection and developing robust infrastructure.
- Addressing confidentiality concerns and achieving interoperability.

Implementing a battery passport system in Kenya is feasible but requires addressing these challenges through collaboration and robust infrastructure development.

References

(n.d.). Retrieved August 26, 2024, from SMART STRING ENERGY STORAGE SYSTEM: https://solar.huawei.com/download?p=%2F-%2Fmedia%2FSolar%2Fattachment%2Fpdf%2Feu%2Fdatasheet%2FLUNA2000-5_10_15-S0.pdf.

Ahmadi, L., Fowler, M., Young, S. B., Fraser, R. A., Gaffney, B., & Walker, S. B. (2014). Energy efficiency of Li-ion battery packs re-used in stationary power applications. *Sustainable Energy Technologies and Assessments, 8*, 9 - 17.

Andersen, L. (2024, June 17). *Safety Tips for Lithium-ion Battery Transport.* Retrieved August 15, 2024, from Storemasta Blog: https://blog.storemasta.com.au/safety-tips-for-lithium-ion-battery-transport.

Battery-Box Lv Flex Lite. (n.d.). Retrieved August 26, 2024, from BYD Battery-Box: https://www.bydbatterybox.com/uploads/downloads/Battery-Box%20LV%20Flex%20Lite%20V1.1%20EN-619cb74d1183d.pdf.

Battery-Box Premium Hvs / Hvm. (n.d.). Retrieved August 26, 2024, from BYD Battery-Box: https://bydbatterybox.com/uploads/downloads/BYD%20Battery-Box%20Premium_Datasheet_HV-AU%20V1.2%20EN-5eec6422498ad.pdf.

Beaudet, A., Larouche, F., Amouzegar, K., Bouchard, P., & Zaghib, K. (2020, July 20). *Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials.* Retrieved August 13, 2024, from MDPI: https://www.mdpi.com/2071-1050/12/14/5837.

Bloom, I., Cole, B. W., Sohn, J. J., Jones, S. A., Polzin, E. G., Battaglia, V. S., & Henriksen, G. L. (2001). An accelerated calendar and cycle life study of Li-ion cells. *Journal of Power Sources, 101*(2), 238 - 247.

Bobba, S., Cusenza, M. A., & Talens Piero, L. (2018). Analysis of the future use scenarios of batteries and recycling challenges. *Joint Research Centre (JRC) Technical Reports*.

BU-304a: Safety Concerns with Li-ion. (n.d.). Retrieved August 13, 2024, from Battery University: https://batteryuniversity.com/article/bu-304a-safety-concerns-with-li-ion.

Casals, L. C., Barbero, M., & Corchero, C. (2019). Reused second life batteries for aggregated demand response services. *Journal of Cleaner Production, 212*, 99 - 109.

Casals, L., García, A., & Canal, C. (2018, November 27). *Second life batteries lifespan: Rest of useful life and environmental analysis.* Retrieved from https://www.sciencedirect.com/science/article/pii/S0301479718313124:

Cepisca, C., Enache, B. A., Seritan, G., & Grigorescu, S. D. (2020, August). *Comparative study of screening methods for second life LIFEPO4 batteries.* Retrieved June 26, 2024, from ResearchGate: https://www.researchgate.net/publication/350236060_Comparative_study_of_screening_methods_for_second_life_LIFEPO4_batteries

Eaton. (n.d.). *Europe's largest energy storage system featuring Eaton, Nissan, The Mobility House and BAM now live in the world-famous Johan Cruijff ArenA, Amsterdam.* Retrieved from https://videos.eaton.com/detail/video/5803084260001/europe%E2%80%99s-largest-energy-storage-system-featuring-eaton-nissan-the-mobility-house-and-bam-now-live-in-the-world-famous-johan-cruijff-arena-amsterdam?autoStart=true&page=1&q=stadium.

EN230619-GL-U-GL48100 User Manual V2.0. (n.d.). Retrieved August 26, 2024, from Enertec Batteries: https://enertec.co.za/couch/uploads/file/user-manuals/gl48100-user-manual-v2-0-reading.pdf.

Engel, H., Hertzke, P., & Siccardo, G. (2019, April 30). *Electric vehicles, second life batteries, and their effect on the power sector.* Retrieved August 13, 2024, from McKinsey: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/second-life-ev-batteries-the-newest-value-pool-in-energy-storage.

Fergus, J. W. (2010). Recent developments in cathode materials for lithium-ion batteries. *Journal of Power Sources, 195*(4), 939-954.

Fleckenstein, M., Schmidt, M., Bohlen, O., & Sauer, D. U. (2014). Cell-to-cell variation and aging investigation of lithium-ion cells by electrochemical impedance spectroscopy. *Journal of Power Sources, 196*(11), 5147-5151.

Gao, W., Cao, Z., Kurdkandi, N., Fu, Y., & Mi, C. (2023,). Evaluation of the second-life potential of the first-generation Nissan Leaf battery packs in energy storage systems. Retrieved from https://www.sciencedirect.com/science/article/pii/S2590116824000031?ref=pdf_download&fr=RR-2&rr=8b93fb732ff84ebb.

Gonzales, G., Yu, B., & Bensebaa, F. (2022,). *Development of a Reverse Logistics Modeling for End-of-Life Lithium-Ion Batteries and Its Impact on Recycling Viability—A Case Study to Support End-of-Life Electric Vehicle Battery Strategy in Canada.* Retrieved August 13, 2024, from MDPI: https://www.mdpi.com/2071-1050/14/22/15321.

GOV.UK. (2023,). *A Study on the Safety of Second-life Batteries in Battery Energy Storage Systems.* Retrieved August 13, 2024, from GOV.UK: https://assets.publishing.service.gov.uk/media/63d91ff0e90e0773da7fdb92/safety-of-second-life-batteries-in-bess.pdf

How Long Do Lithium Iron Phosphate (LiFePO4) Batteries Last? (2024,). Retrieved August 26, 2024, from Qurator.com: https://www.qurator.com/blog/how-long-do-lithium-iron-phosphate-batteries-last

IATA. (2021). Dangerous Goods Regulations Manual. International Air Transport Association.

IEC 62660-2:2018 | IEC. (2018, December 12). Retrieved August 13, 2024, from IEC Webstore: https://webstore.iec.ch/en/publication/27387.

jinko 4.8Kwh lithium battery. Retrieved August 26, 2024, from Solargen: https://solargentechnologies.com/wp-content/uploads/2024/03/jinko-4.8Kwh-lithium-battery_compressed.pdf

Kamiya, S., Zhang, X., & Tzeng, Y. (2021). Technical Evaluation of Second-Life Batteries for Grid Energy Storage Applications. *IEEE Access, 9*.

Laserna, E. M., Zabala, E. S., D, I. S., Swierczynski, M., Warnecke, A., Timmermans, J. M., & Goutam, S. (2018). Evaluation of lithium-ion battery second life performance and degradation. *Journal of Energy Storage, 11*, 200 - 210.

Lithium battery transport: all you need to know. (2022,). Retrieved August 15, 2024, from Flash Battery: https://www.flashbattery.tech/en/lithium-battery-transport/.

Lumkong, D., & Davis, S. (2024,). *Electric Vehicle Battery Repurposing and Second Life.* Retrieved August 19, 2024, from battery infosheet 4: https://www.no-burn.org/wp-content/uploads/2024/06/04-Battery-Infosheet-Electric-Vehicle-Battery-Repurposing-and-Second-Life.pdf

Narula, R., Kaiser, J., & Ramadesigan, V. (2020). Mechanical aging and its impact on the lifetime of lithium-ion batteries: A critical review. *Journal of Power Sources, 466*(228291).

Patel, A. N., Lander, L., Ahuja, J., & Bulman, J. (2024,). *Lithium-ion battery second life: pathways, challenges and outlook.* Retrieved June 27, 2024, from NCBI: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11033388/#s3title

Patel, A. N., Lander, L., Ahuja, J., Bulman, J., Lum, J. K., Pople, J. O., . . . Edge, J. S. (2024,). *Lithium-ion battery second life: pathways, challenges and outlook.* Retrieved August 13, 2024, from NCBI: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11033388/

PDF File. Retrieved August 26, 2024, from Enertec Batteries: https://enertec.co.za/couch/uploads/file/spec-sheets/gl-series-specifications-enertec.pdf.

Pratt, D. (2018,). *Inside the Amsterdam ArenA, home to Europe's largest stadium battery.* Retrieved August 19, 2024, from Current: https://www.current-news.co.uk/inside-the-amsterdam-arena-home-to-europes-largest-stadium-battery/.

Redondo-Iglesias, E., Venet, P., Pelissier, S., & Bardet, M. (2018). Global Model for the Reuse of Electric Vehicle Batteries in Stationary Applications. *IEEE Transactions on Vehicular Technology, 67*(2), 1047 - 1055.

Rufino, C. A., Sanseverino, E. R., Gallo, P., Koch, D., Schweiger, H.-G., & Zanin, H. (2023,). *Blockchain review for battery supply chain monitoring and battery trading.* Retrieved from Science Direct: https://www.sciencedirect.com/science/article/abs/pii/S1364032122000089.

Safely Storing Lithium-Ion Batteries: Why Do You Need Specialist Storage? (2023,). Retrieved August 15, 2024, from Empteezy: https://www.empteezy.co.uk/blogs/editorial/safely-storing-lithium-ion-batteries-why-do-you-need-specialist-storage

Shenzhen Growatt New Energy Co., Ltd. (n.d.). *AXE 5.0L Modular Battery.* Retrieved August 26, 2024, from https://www.alternergy.co.uk/media/mageplaza/product_attachments/attachment_file/g/r/growatt_axe_5.0_lv_battery_datasheet_-_05_05_2022_1.pdf.

Stretton, C. (2023,). *EU battery passport regulation requirements.* Retrieved August 14, 2024, from Circularise: https://www.circularise.com/blogs/eu-battery-passport-regulation-requirements.

Sura, M. (2022,). *2010 Nissan Leaf.* Retrieved August 13, 2024, from Battery Design: https://www.batterydesign.net/2010-nissan-leaf/.

United Nations. (2017). UN Manual of Tests and Criteria. *6*.

USER GUIDE. (n.d.). Retrieved August 26, 2024, from Felicity Solar: https://www.felicitysolar.com/u_file/2311/16/file/LPBF-SSpecifications.pdf.

Waldmann, T., Wilka, M., Kasper, M., Fleischhammer, M., & Wohlfahrt-Mehrens, M. (2014). Temperature dependent ageing mechanisms in Lithium-ion batteries – A Post-Mortem study. *Journal of Power Sources, 262*, 129 - 135.

Wang, D., Kulp, C. W., DeMarco, C. L., & Haldar, P. (2019). Cycle life and capacity retention in second-life applications of electric vehicle batteries. *Journal of Power Sources, 435*.

Weco Dual Voltage 5k3-Xp. (n.d.). Retrieved August 26, 2024, from Squarespace: https://static1.squarespace.com/static/6005e6d63294c7562433d2bd/t/6399effe568af374d291bfa8/1671032831349/5K3+XP+Datasheet.pdf.

Zhang, W., Tang, Z., Jia, L., & Zhang, X. (2018). Battery state of health estimation: A concise review. *Renewable and Sustainable Energy Reviews, 113*(109230).