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Advancing Battery Circularity

A focus on Battery Degradation, Skills, and Strategies for a Sustainable Future

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List of Acronyms

AC	Alternating Current
BEPA	Battery European Partnership Association
BMS	Battery Management System(s)
CAN	Controller Area Network
DC	Direct Current
DCFC	Direct Current Fast Charging
DoD	Depth of Discharge
DPR	Declared Performance Requirements
EBA	European Battery Alliance
ECUs	Electronic Control Units
EIS	Electrochemical Impedance Spectroscopy
EIT	European Institute of Innovation and Technology
EOL	End-of-Life
EPR	Extended Producer Responsibility
ESS	EV Packs in Stationary Storage
EU	European Union
EV	Electric Vehicle
EVs	Electric Vehicles
GTR	Global Technical Regulation
GWh	Gigawatt-hour
HV	High Voltage
ICA	Incremental Capacity Analysis
ICE	Internal Combustion Engine
ID	Identification
IEA	International Energy Agency
ILO	International Labour Organisation
KEBS	Kenya Bureau of Standards
LCR	Local Content Requirement
LIBs	Lithium-Ion Batteries
MPR	Minimum Performance Requirements
NGOs	Non-Governmental Organizations
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory

OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
OVC-HEVs	Off-Vehicle Charging Hybrid Electric Vehicles
PEVs	Plug-in Electric Vehicles
PPE	Personal Protective Equipment
SEI	Solid Electrolyte Interphase
SoC	State of Charge
SOCE	State of Certified Energy
SOCR	State of Certified Range
SoH	State of Health
SOPs	Standard Operating Procedures
TCO	Total Cost of Ownership
TN	Technical Note
ToT	Train-the-Trainer
TVET	Technical and Vocational Education and Training
UN	United Nations
USD	United States Dollar
VCM	Vehicle Control Module

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Acknowledgements

This report is part of the project *"Techno-Economic Viability of Second-Life Applications for Electric Vehicle Batteries in Kenya"*, prepared by Knights Energy.

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We also want to thank all of the stakeholders, technicians, and participants who provided insights, expertise, and practical support to ensure that this report accurately reflects both technical rigour and the realities of Kenya's electric transportation scenario.

Executive Summary

This report presents a comprehensive analysis of the technical, operational, and policy dimensions required to advance electric vehicle (EV) battery circularity in Kenya. It focuses on three critical pillars: battery degradation, consumer perceptions, and workforce readiness, to inform scalable strategies for sustainable EV adoption.

Key findings include:

- Battery Degradation: Lithium-ion battery performance declines due to capacity and power fade, driven by electrochemical changes and exacerbated by environmental stressors. Comparative analysis shows that advanced thermal management systems and moderated charging practices significantly reduce degradation rates. Recommendations emphasise improved diagnostics, predictive analytics, and standardised health reporting.
- Consumer Perceptions: Survey and qualitative data reveal that over 70% of respondents express concerns tied to battery reliability, range anxiety, and replacement costs. Trust in repurposed batteries remains low due to limited awareness, safety concerns, and unclear warranty implications. Targeted communication, labelling transparency, and technician training are proposed to strengthen consumer confidence.
- Pilot Battery Replacement: A retrofit of a degraded 24 kWh battery with a 40 kWh pack in a Nissan Leaf demonstrated the technical feasibility of local battery replacement. The pilot highlighted challenges in mechanical handling, documentation gaps from the OEM, and component compatibility, underscoring the need for standard operating procedures, certified technicians, and retrofit-friendly supply chains.
- Skills and Equipment Assessment: Kenya has a foundation in battery handling, particularly for electric two- and three-wheelers, as these vehicles are assembled locally. However, the country lacks advanced skills for handling electric four-wheelers and electric buses, as well as access to specialised tools. International models, such as the European Battery Alliance Academy and Train-the-Trainer frameworks, provide scalable solutions. Recommendations for improvement include establishing accredited programs, enhancing access to equipment, and institutionalising green skills within national policy.
- Policy Recommendations: The report outlines actionable guidelines across five domains, which are performance transparency, repair and replacement safety, consumer trust, workforce development, and enabling infrastructure. It calls for regulatory support, financial incentives, and public-private partnerships to accelerate battery circularity.

By addressing degradation, building consumer trust, and investing in technician capacity, Kenya can position itself to advance EV battery lifecycle management. The findings support the development of a sustainable, inclusive, and technically robust framework for electric mobility.

1 Introduction

The global shift toward electric mobility and renewable energy integration has placed lithium-ion batteries (LIBs) at the centre of technological innovation. These batteries power electric vehicles (EVs) and provide storage for intermittent renewable energy sources, positioning them as a cornerstone of the transition to sustainable energy systems. However, the performance and long-term reliability of LIBs are challenged by battery degradation, a gradual and irreversible process that reduces both storage capacity and power output. Understanding the mechanisms, patterns, and impacts of battery degradation is therefore essential for ensuring the sustainability, safety, and affordability of EV adoption, particularly in emerging markets such as Kenya.

Battery degradation manifests through two primary outcomes: capacity fade, which reduces the total energy available, and power fade, which limits performance. These changes result from electrochemical and structural transformations within the battery, including growth of the solid electrolyte interphase (SEI), lithium plating, and electrode deterioration. Environmental and operational factors such as high temperatures, rapid charging, and deep discharge cycles further accelerate these processes. Consequently, battery degradation not only shortens vehicle range but also raises consumer concerns about replacement costs, second-hand EV value, and end-of-life (EOL) management.

Despite ongoing advancements in EV battery technology, degradation remains a key barrier to widespread adoption. In contexts such as Kenya, where most vehicles are imported second-hand, the challenge is amplified as many EVs may arrive with already degraded batteries. The absence of structured battery replacement, repair, and repurposing ecosystems risks rendering these vehicles uneconomical and undermining the country's transition to clean mobility. Additionally, there are significant gaps in technician skills, diagnostic capacity, and public awareness of battery lifecycle management. Without targeted interventions, degradation could exacerbate consumer mistrust, limit EV uptake, and hinder sustainable circular economy practices.

As Kenya accelerates its adoption of electric mobility, addressing the challenge of battery degradation is critical to ensuring long-term sustainability. Understanding degradation patterns and developing localised solutions for replacement, repair, and reuse can prevent premature vehicle obsolescence, lower the total cost of ownership, and strengthen consumer confidence.

2 Investigating Battery Degradation

2.1 Literature Review

Battery degradation is a critical factor influencing the performance and longevity of lithium-ion batteries (LIBs), which are widely used in electric vehicles (EVs) and stationary energy storage systems. Understanding the mechanisms and patterns of battery degradation is essential for developing strategies to extend battery life and improve energy storage reliability. Degradation primarily manifests as capacity fade and power fade, both driven by chemical and structural changes within the battery over time. Key mechanisms include the growth of the solid electrolyte interphase (SEI), lithium plating, and electrode material deterioration, all of which can be accelerated by factors such as elevated temperatures, high charge/discharge rates, and deep depth of discharge (DoD) cycles.[1]

To effectively investigate battery degradation, proper data collection and preparation are crucial. Essential battery health parameters such as State of Charge (SoC), State of Health (SoH), internal resistance, cycle count, capacity retention, voltage, and temperature must be monitored consistently. Data collection methods range from controlled laboratory cycling tests to real-world data acquisition through Battery Management Systems (BMS) and software tools like MATLAB and PyBaMM.[2] Such data plays a foundational role in developing degradation models and informing predictive analytics.[3]

Analysing degradation patterns involves applying techniques such as Electrochemical Impedance Spectroscopy (EIS), Incremental Capacity Analysis (ICA), and machine learning models.[4] These methods help reveal degradation behaviours, such as sudden capacity loss (knee points) and the distinctions between calendar ageing and cyclic ageing. This data-driven approach aids in understanding the complex interactions between operational conditions and battery health over time.

To mitigate battery degradation and extend lifespan, technical recommendations focus on operational and design improvements. Strategies such as maintaining moderate SoC ranges (typically 20-80%), minimising exposure to high temperatures, and integrating advanced BMS algorithms for balanced charging have proven effective. Further, advancements in battery materials, including silicon anodes and solid-state electrolytes, offer promising pathways for enhancing battery durability and energy density.

[1] Impact of temperature and state-of-charge on long-term storage degradation in lithium-ion batteries: an integrated P2D-based degradation analysis - RSC Advances (RSC Publishing) DOI:10.1039/D5RA03735B
[2] Lithium-ion battery degradation: how to model it - Physical Chemistry Chemical Physics (RSC Publishing)
[3] Battery State of Health Estimate Strategies: From Data Analysis to End-Cloud Collaborative Framework
[4] Data-driven prediction of battery cycle life before capacity degradation

2.2 Analysis of Degradation Patterns

EV battery degradation is a natural process that permanently reduces the amount of energy a battery can store or the amount of power it can deliver.[5] According to a study conducted by Geotab, robust thermal management systems greatly slow down battery degradation.

As shown below, the 2015 Tesla Model S, which employs liquid cooling, had an average degradation rate of 2.3% whereas the 2015 Nissan Leaf, which uses passive air cooling, showed a higher rate of 4.2%. Analysis of battery health done in 2019 revealed a degradation rate of 2.3% per year, while a similar study in 2024 revealed an improvement to an average of 1.8% yearly. This was attributed to ongoing advancements in battery technology and durability. The figure below shows battery degradation rates for 11 analysed EV models

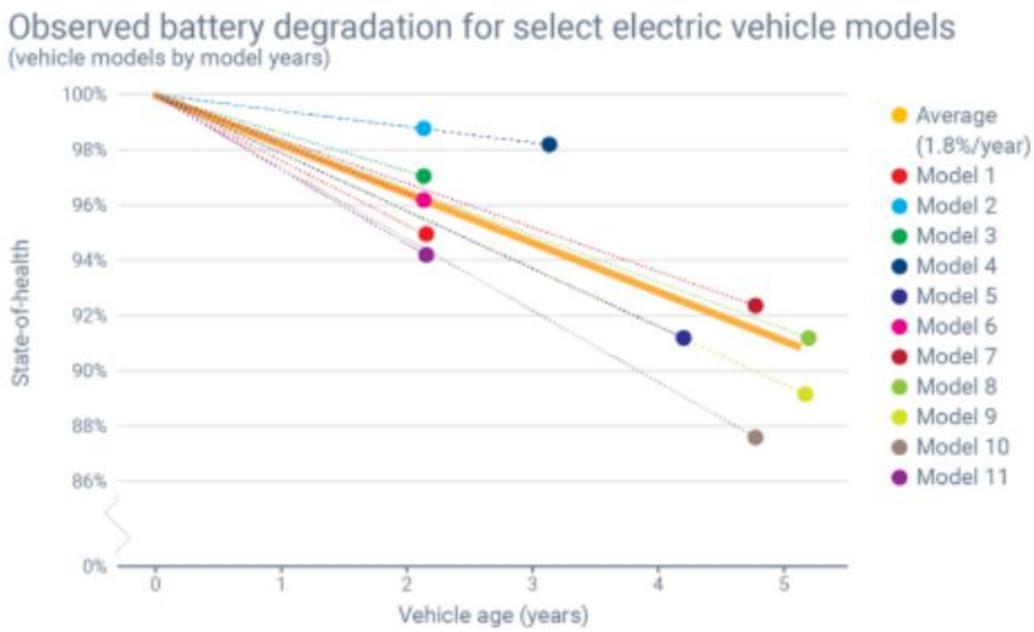

Figure 1 Battery degradation rates for 11 EV models analysed[6]

Frequent use of DC fast charging can accelerate battery degradation, especially in hot climates, while level 2 charging is gentler on the battery. Keeping the SOC between 20% - 80%, minimising exposure to extreme temperatures and limiting fast charging can extend battery life.

[5] The Science Behind EV Battery Degradation and How to Mitigate It | Midtronics

[6] EV Battery Health Insights: Data From 10,000 Cars | Geotab

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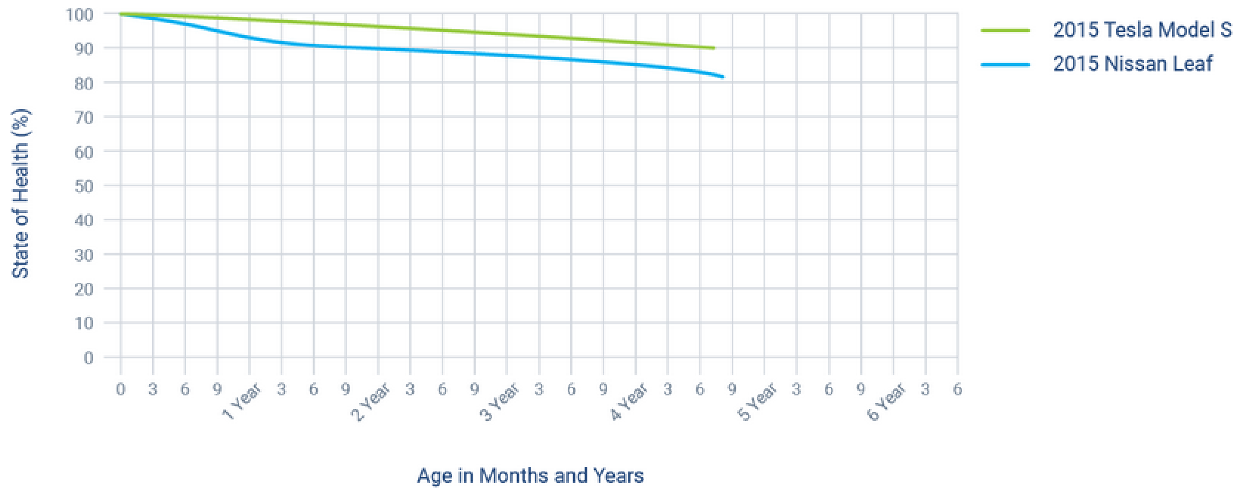

Figure 2 Battery degradation comparison of 2015 Tesla Model S (liquid cooling) vs. 2015 Nissan Leaf (passive air cooling)[6]

Temperature is another factor that affects battery degradation rate. EV batteries exposed to extreme heat degrade faster than those in cooler climates. Vehicles were studied in two climates and grouped as described below:

- Temperate - Less than five days per annum over 80°F (27°C) or under 23°F (-5°C)
- Hot - More than five days per year over 80°F (27°C)

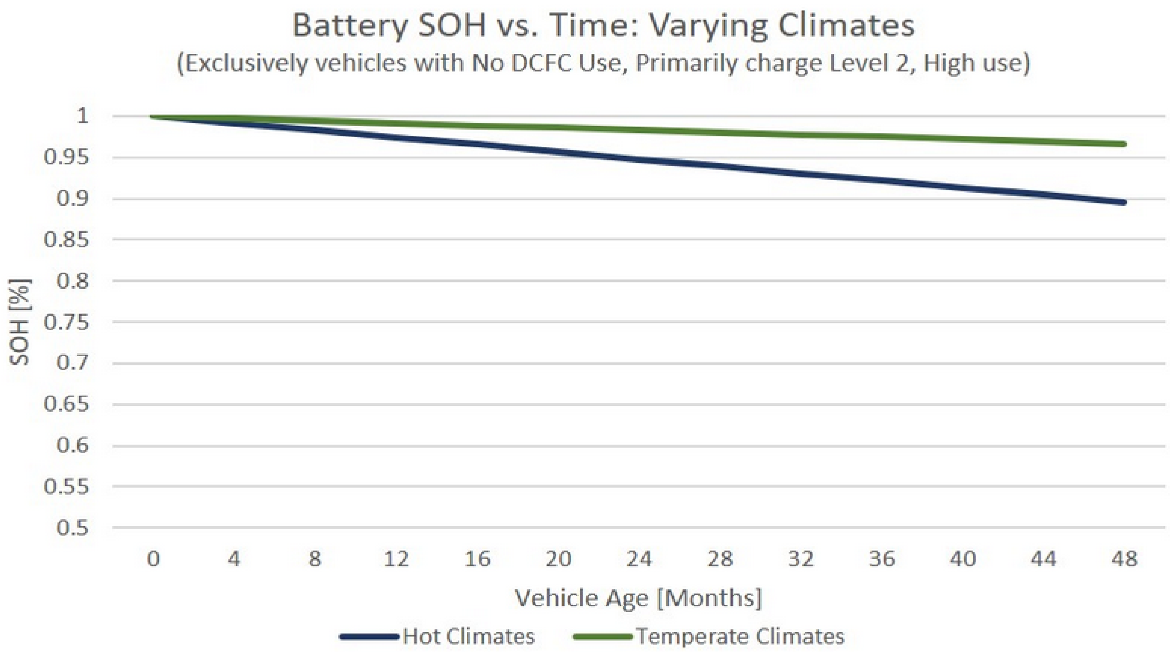

Figure 3 Batteries exposed to hot days degrade faster than those in temperate climates[6]

High frequency of use of EVs does not significantly increase the battery degradation rate[6], an encouraging finding, since EVs deliver better value when driven more frequently. However, frequent use of DC fast charging for high-use vehicles may contribute to faster degradation.

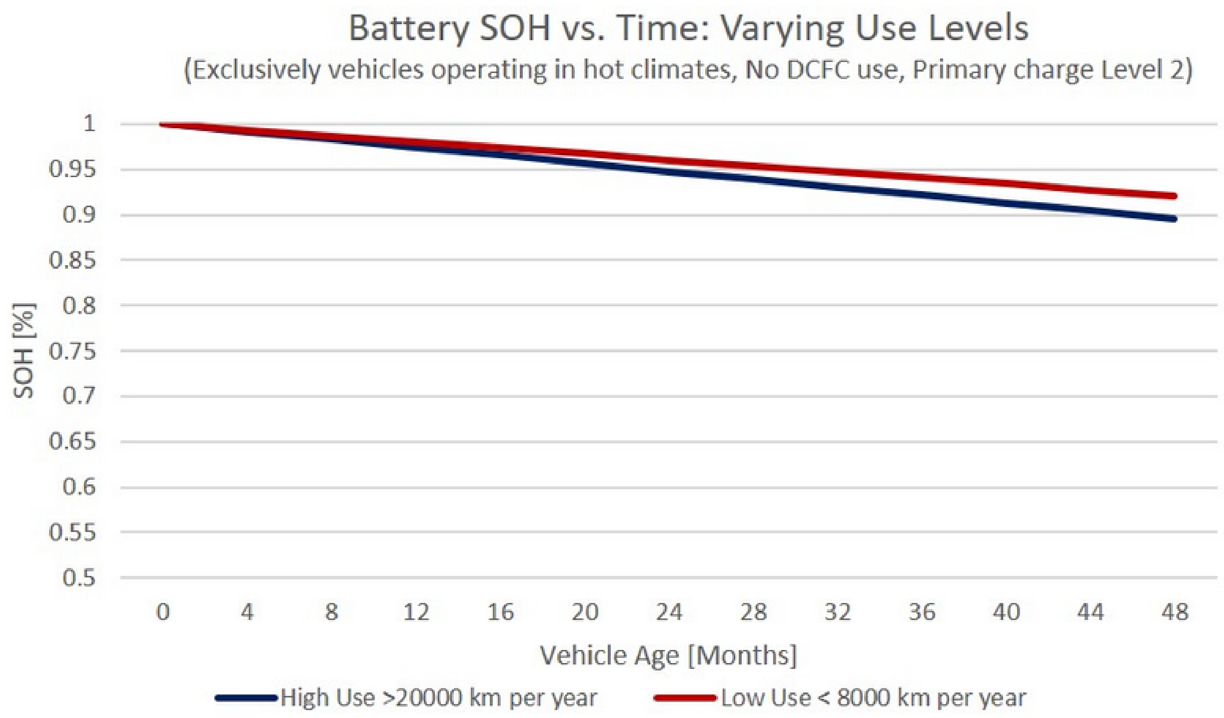

Figure 4 Frequency of use has a small impact on average degradation rates[6]

The study examined the predominant charging levels used for EVs in their system and observed a difference in battery health between cars that routinely charge on Level 2 and those that use Level 1. The difference, however, was not statistically significant. Common North American EV charging stations are categorised into the following three common types:

- AC Level 1 (120 volts) - a regular home outlet in North America
- AC Level 2 (240 volts) - typical for home or fleet charging
- Direct Current Fast Charging (DCFC) - for faster top-ups

The use of DCFC equipment, on the other hand, appeared to have a significant impact on the rate of battery degradation. Rapid charging means high current that results in high temperatures, both of which strain the batteries.

Below is a comparison of all battery electric vehicles operating in hot climate conditions based on how frequently they used a DCFC: never, occasionally (0-3) times per month or frequently (3+ times per month).

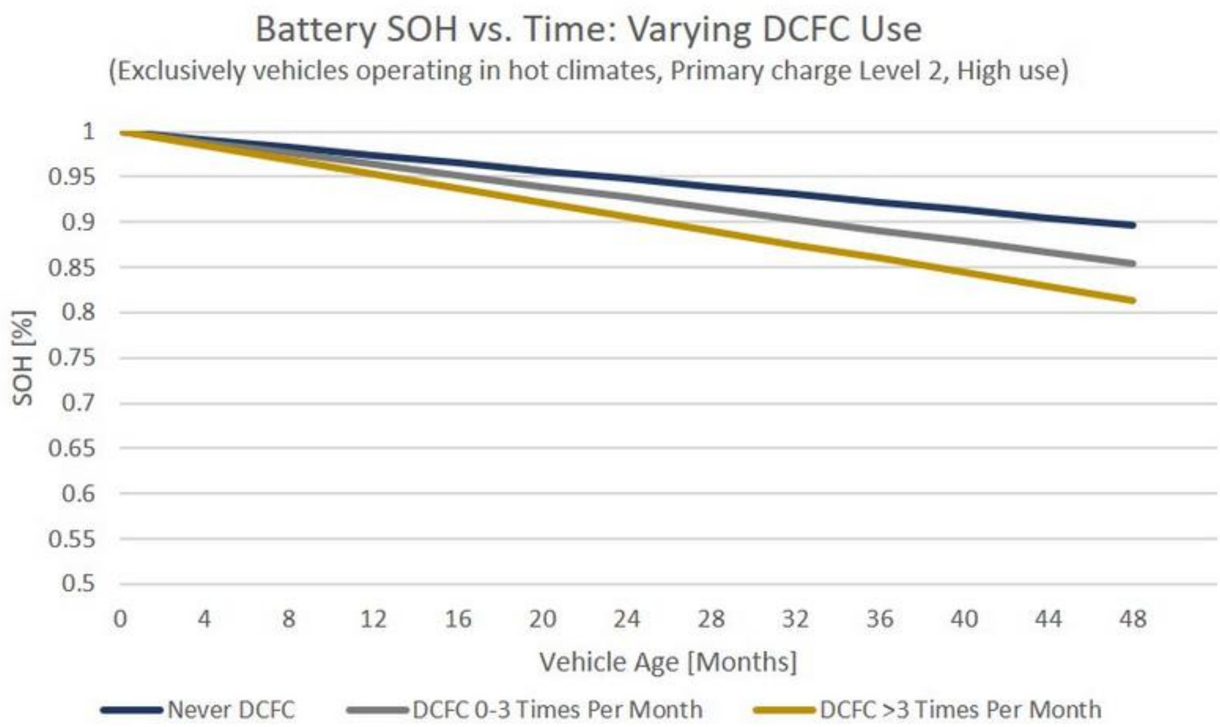

Figure 5 Battery SOH against Time: Variation on DCFC Use[6]

The State of Charge is the amount of energy that an EV battery holds compared to its full capacity. A battery at full charge is at 100% SOC, while one that is completely discharged is at 0% SOC. The usable charge is usually lower because of charging buffers implemented by the manufacturer to protect the battery's health. Using a battery near full or empty can degrade its lifespan. Some manufacturers allow users to set a custom charge limit, helping extend battery life.

2.3 Conclusions

Battery degradation remains one of the most significant challenges to the performance, reliability, and sustainability of lithium-ion batteries (LIBs) in electric vehicles (EVs) and stationary storage systems. Evidence shows that degradation manifests mainly as capacity fade and power fade, driven by mechanisms such as solid electrolyte interphase (SEI) growth, lithium plating, and electrode deterioration. Environmental conditions, charging practices, and battery management play a critical role in accelerating or slowing degradation.

Advanced thermal management systems (e.g., liquid cooling in Tesla vehicles) can substantially reduce degradation rates compared to passive air-cooling systems (e.g., Nissan Leaf). Additionally, charging behaviours strongly influence degradation: frequent use of DC fast charging accelerates wear, particularly in hot climates, while moderate charging cycles (20–80% State of Charge) and Level 2 charging help extend battery lifespan.

Data also highlights positive trends: degradation rates are improving, with annual averages dropping from ~2.3% to ~1.8% in recent studies, owing to technological advancements in materials, battery design, and management algorithms. This indicates that ongoing innovation can further enhance durability, provided that best practices are adopted by users, manufacturers, and policymakers.

2.4 Recommendations

1. Strengthening Monitoring and Diagnostics
    - Expand the use of Battery Management Systems (BMS) with advanced algorithms to track State of Health (SoH), cycle life, and thermal conditions in real time.
    - Encourage development of predictive maintenance tools that use data analytics, machine learning, and Incremental Capacity Analysis (ICA) to anticipate knee points of sudden degradation.
2. Standardise Testing and Reporting
    - Establish national or regional guidelines for battery health reporting, like EU battery passport initiatives, requiring disclosure of degradation rates and expected lifespans.
    - Mandate standardised testing protocols for manufacturers to ensure transparency and consumer confidence in second-life applications.
3. Foster Consumer Awareness and Behaviour Change
    - Implement public education campaigns to address misconceptions around EV battery lifespan, degradation rates, and replacement costs.
    - Provide clear information on recycling, reuse, and second-life opportunities to strengthen consumer trust in end-of-life (EOL) management.
4. Invest in R&D and Skills Development
    - Support local research institutions and training centres in developing expertise in degradation diagnostics, second-life testing, and recycling technologies.
    - Build skills in high-voltage safety, BMS programming, and predictive analytics to strengthen workforce readiness for EV battery circularity.

3 Gauging Customer Perceptions

Understanding consumer perceptions of electric vehicle (EV) battery performance and end-of-life (EOL) management is critical for fostering adoption and developing sustainable practices. One of the most persistent barriers is range anxiety, the fear of running out of battery before reaching a charging station. Despite advances in battery technology, it remains a key deterrent to purchase, particularly in regions with limited infrastructure. For instance, European consumers increasingly expect a minimum 500 km driving range before considering a switch to EVs, with many current EV owners dissatisfied with real-world range performance.[7]

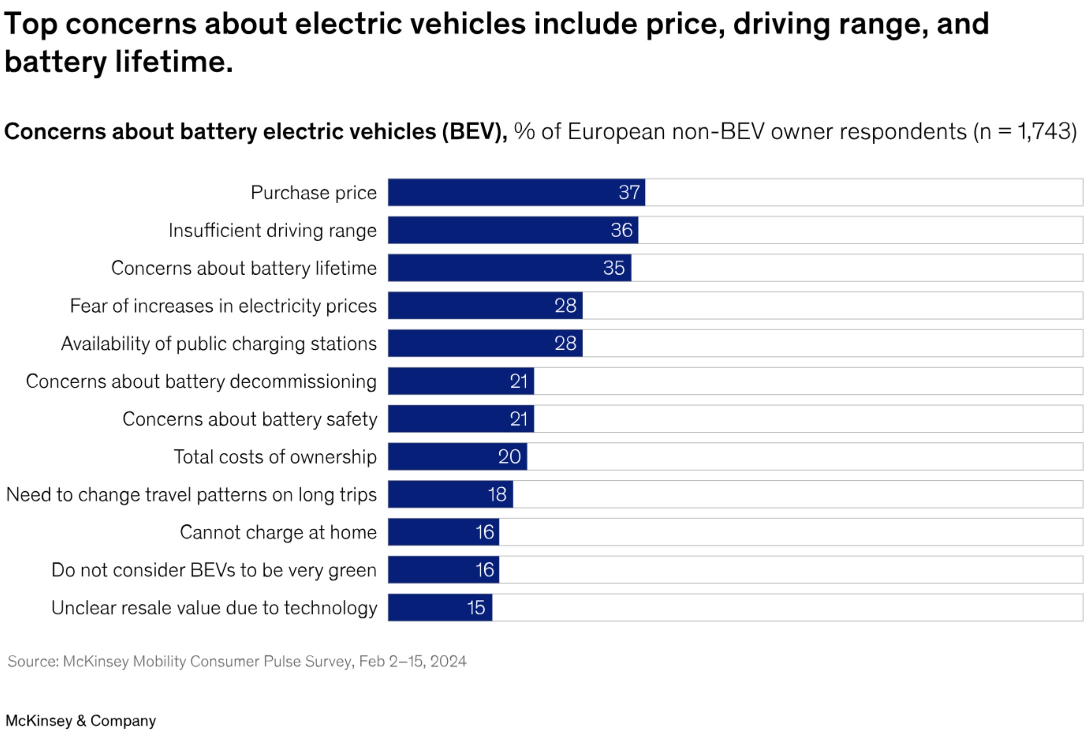

Figure 6 Top Concerns About EVs from Europeans (Source: McKinsey & Company)

Concerns over battery degradation and replacement costs also shape consumer trust. Analysis by Geotab indicates that EV batteries degrade at an average rate of about 2% per year, but uncertainties remain around long-term reliability. Replacement costs, estimated between USD 5,000–20,000 depending on the vehicle model, exacerbate consumer hesitation.[8]

The availability and accessibility of charging infrastructure significantly influence consumer satisfaction. Inadequate networks and long charging times contribute to frustration, whereas fast-charging and home charging solutions improve confidence. This can be specifically identified as driving range and recharging time as decisive factors in shaping EV user satisfaction.

[7] Consumer perceptions of electric vehicles in Europe | McKinsey
[8] $20,000 repair bills and other hidden costs that could sneak up on EV buyers | Business Insider Africa

When it comes to end-of-life (EOL) management, many consumers express concern about the environmental impacts of battery disposal but lack awareness of reuse and recycling programs. This knowledge gap undermines trust in EV sustainability.[9] Strong regulatory frameworks and awareness campaigns around recycling are viewed as critical to consumer confidence.

The repurposing of retired EV batteries for secondary uses such as stationary energy storage has emerged as a promising solution. Even after retirement from vehicles, lithium-ion batteries typically retain enough capacity, making them suitable for residential, commercial, or grid storage. By 2030, an estimated 112–275 GWh of second-life batteries could become available annually worldwide.[10] However, consumer acceptance is mixed, with concerns about reliability, warranties, and business models slowing wider adoption.

There are emerging global examples of successful second-life applications. In Japan, retired EV batteries are repurposed for grid storage in renewable energy systems, and companies like Nissan have launched programs using second-life batteries in residential storage solutions.[11] Yet, socio-cultural factors also shape perceptions: in some regions, preferences for internal combustion engine (ICE) vehicles persist, often due to misconceptions about battery safety and sustainability. Addressing these barriers through education, outreach, and transparent communication is vital for building long-term consumer trust in EV battery circularity.

3.1 Methodology, Data Analysis, and Results

3.1.1 Methodology

To assess consumer perceptions and technical awareness surrounding EV battery replacement and repurposing, a mixed-methods approach was employed across three primary data collection channels:

Direct Interactions at Exhibitions and Events - Semi-structured conversations were conducted with attendees at EV-focused exhibitions where repurposed battery packs were showcased. These interactions captured spontaneous feedback, technical inquiries, and consumer sentiment regarding battery replacement feasibility, safety, and value.

- **Questionnaires and Survey Instruments** - A standardised questionnaire was conducted, targeting EV users and prospective EV buyers. The survey included multiple-choice and open-ended questions focused on perceived challenges and battery lifecycle concerns.

[9] Regional distribution and losses of end-of-life steel throughout multiple product life cycles—Insights from the global multiregional MaTrace model - ScienceDirect
[10] Electric vehicles, second life batteries, and their effect on the power sector | McKinsey
[11] Nissan gives EV batteries a second life | Stories | Nissan Motor Corporation Global Website

3.1.2 Data Analysis

- Quantitative Analysis
    - Survey responses (n=501) were analysed using descriptive statistics to identify dominant concerns and adoption barriers. Frequency distributions and percentage breakdowns were used to rank challenges such as range anxiety, cost, and technical support gaps.
- Qualitative Thematic Analysis
    - Feedback from direct interactions was analysed into thematic categories. Key themes included:
        - *Trust and Safety*: Concerns over the reliability of repurposed batteries
        - *Cost Sensitivity*: Interest in affordable alternatives to OEM replacements
        - *Technical Curiosity*: Inquiries about installation, compatibility, and diagnostics.

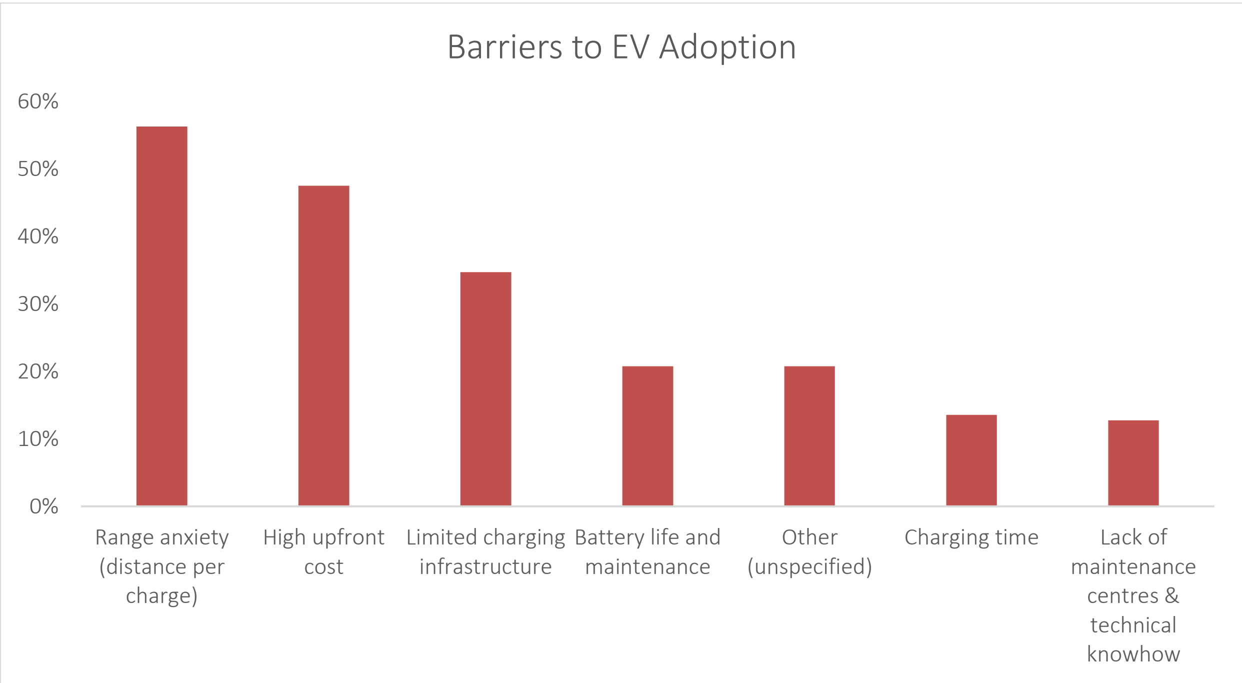

Figure 7 Barriers to EV Adoption

When the respondents were asked to select significant challenges in adopting EVs, the following feedback came out:

- Battery-Related Concerns Dominate
    - When combining responses related to range anxiety (selected by **55.84%** of participants) and battery life and maintenance (selected by **20.59%**), it becomes

evident that over **70%** of respondents expressed concerns directly tied to battery performance and lifecycle management.

- Range anxiety reflects widespread apprehension about limited driving distance per charge and inadequate charging predictability, while concerns about battery life and maintenance highlight uncertainty regarding long-term reliability, degradation, and replacement costs.

- Technical Capacity
    - Battery life management was selected by 12.67% of respondents who cited the lack of maintenance centres and technical know-how highlight a critical constraint to scaling EV adoption, particularly in areas involving battery diagnostics, replacement, and post-warranty servicing.
    - This data point underscores a broader shortage of certified technicians and the absence of localised infrastructure capable of supporting high-voltage battery systems.

3.1.3 Consumer Perception on Repurposed EV Batteries

The qualitative data were gathered from direct engagements at exhibitions where repurposed battery packs were displayed. The inquiries reflected consumer attitudes, knowledge gaps, and adoption barriers related to second-life EV batteries. The findings were grouped into thematic categories to inform communication strategies, product development, and policy engagement. The table below gives the thematic categories:

Table 1 Consumer Perception on Repurposed EV Batteries

Theme	Representative Questions	Key Insight
Longevity & Reliability	"How long will these repurposed batteries last?" "How do I know this battery still has enough capacity?"	Consumers seek assurance on lifespan and residual capacity. Performance metrics should be visible and validated.
Safety & Standards	"Are second-life batteries safe?" "How do I know these aren't fake or used-up batteries?"	Safety concerns dominate. Clear communication on testing, certification, and fire prevention is essential.

Trust & Quality Assurance	"How do I know these aren't fake or used-up batteries?"	Transparency in sourcing, labelling, and third-party verification builds trust.
Use Case Awareness	"What kind of applications can I use them for?" "Can these batteries be used in solar home systems?"	Consumers are unaware of viable applications. Education on home storage, backup, and solar integration is needed.
Affordability & Value	"How much cheaper is this than buying a new battery?"	Price is a key motivator. Clear cost-benefit comparisons should be part of marketing.
Warranty & Compatibility	"Will this void my car's warranty if I use a second-life battery?"	Legal and OEM concerns hinder adoption. Requires engagement with manufacturers and policy clarity.
Lifecycle & Sustainability	"What happens when even this battery dies – is there a recycling plan?" "What's the environmental impact?"	Consumers value sustainability but want proof. Lifecycle plans and environmental impact data should be shared.
Installation & Accessibility	"Can I install this myself, or do I need a technician?"	Simplicity matters. Training programs and installation support can improve accessibility.
Policy & Incentives	"Are there any government incentives for using these?"	Low awareness of incentives. Public education and policy advocacy are needed.

3.2 Conclusion

The findings from this study underscore a multifaceted set of consumer concerns and systemic gaps surrounding EV battery replacement and repurposing. Quantitative survey data revealed that over **70% of respondents** expressed apprehension directly tied to battery performance, including range anxiety, degradation, and maintenance costs. Additionally, **12.67%** cited the lack of technical support and maintenance infrastructure as a critical barrier to adoption—highlighting the urgent need for technician training and service network expansion.

Qualitative insights from exhibition engagements further reinforced these themes. Visitors raised questions about safety, reliability, affordability, and compatibility, revealing a widespread lack of awareness regarding second-life battery applications and lifecycle management. Trust in repurposed batteries remains fragile, shaped by perceptions of risk, limited technical literacy, and the absence of visible performance metrics.

Collectively, these findings underscore a strategic imperative for building consumer confidence, technical capacity, and policy alignment to support scalable, safe, and economically viable battery replacement ecosystems.

The table below provides targeted recommendations for improving customer perception of repurposed EV batteries.

Table 2 Targeted Recommendation on Repurposed EV Batteries

Focus Area	Recommendation	Responsible Stakeholders
Battery Performance Transparency	Implement standardised labelling showing SoH, cycle count, and residual capacity on repurposed packs.	Manufacturers and Assemblers
Safety Assurance	Mandate third-party testing and certification for repurposed batteries; publish fire safety protocols.	Standards Bodies, Regulatory Agencies
Technician Training	Launch certified training programs focused on HV battery diagnostics, replacement, and safety handling.	Local training and certification institutes
Use Case Education	Develop consumer-facing materials illustrating second-life battery applications (e.g., solar, backup).	Private sector, NGOs, Energy Access Programs, Product Developers
Affordability Communication	Provide clear cost-benefit comparisons between new and repurposed batteries, including TCO estimates.	Retrofit Providers, Consumer Advocacy Groups
Warranty & Legal Clarity	Engage OEMs to define retrofit boundaries and clarify warranty implications for second-life installations.	Automotive Manufacturers, Legal Advisory Bodies
Lifecycle Management	Establish end-of-life recycling pathways and communicate the	Circular Economy Initiatives, Environmental Agencies

	environmental benefits of reuse models.	
Installation Support	Offer technician-assisted installation services and guidance for safe deployment.	Retrofit Providers, training institutions.
Policy & Incentives	Advocate for government incentives, tax relief, or subsidies for repurposed battery adoption.	Policy Makers, Industry Associations
Public Awareness Campaigns	Launch targeted outreach to improve consumer understanding of battery health, safety, and reuse value.	Media Partners, Civil Society Organisations

4 Pilot Replacement of EV Batteries

4.1 Introduction

The pilot replacement of a degraded 24 kWh traction battery pack in a 2011 Nissan Leaf with a 40-kWh pack was undertaken to assess the practical feasibility of battery replacement in Kenya's emerging EV ecosystem. This initiative is critical given that over 80% of vehicles entering the Kenyan market are second-hand imports; a similar trend in electric vehicles would imply that many units arrive with significantly degraded batteries, which are difficult to replace locally. Without local replacement or repair solutions, these vehicles face short usable lives, undermining adoption.

This pilot focused on a real-world case where the original battery had degraded to 37% SoH, limiting range on a full charge, insufficient for either private use or taxi operations. The replacement demonstrated the technical, operational, and safety considerations necessary for extending the vehicle's life and improving its range. While the emphasis here is on full-pack replacement, it is important to acknowledge that battery repair (module-level refurbishment) offers an alternative strategy. Repair is cost-effective when degradation is localised, but replacement provides uniformity, reliability, and extended performance.

4.2 Battery Replacement Process

4.2.1 Pre-Replacement Diagnostics

Battery diagnostics (Leaf Spy, OBD-II, and internal resistance testing) confirmed severe degradation in the 24-kWh pack. Before removal, safety checks, including insulation resistance and voltage verification, were completed. The figure below presents the Leaf Spy results from the pre-replacement diagnostics.

The battery SOH was at 37.74% with a voltage of 356.61V, with an Hx of 36.13% (Hx is a key indicator of high-voltage (HV) battery health. A value near 100 represents a factory-new battery with minimal internal resistance). As Hx declines, internal resistance rises, causing more energy to be lost as heat instead of being delivered to power the vehicle.

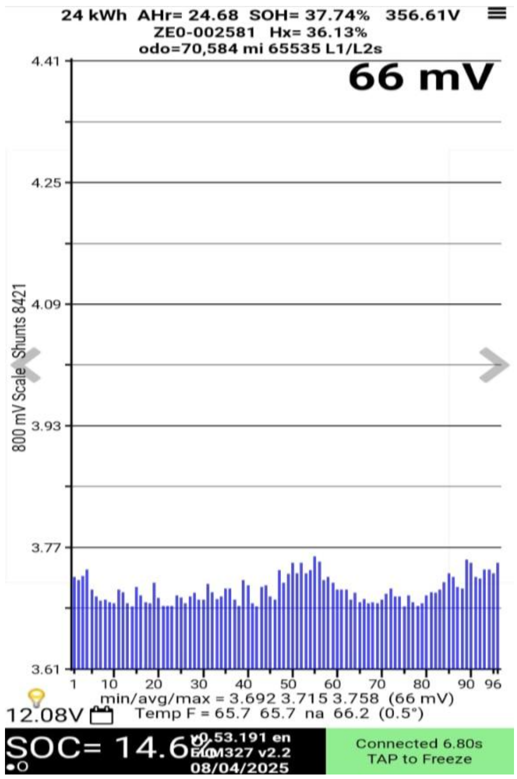

Figure 8 Leaf Spy Diagnostics Report

4.2.2 Battery Specifications

The Original Pack was a 24 kWh, 48-module arrangement in 2 layers. The new Replacement Pack was made up of a 40 kWh, 16 modules, each in a 6S1P configuration (6 cells in series per module). The Electrical characteristics of the new battery pack each module 22.2 V, nominal capacity of 114 Ah, a charge rate of 1C and a discharge 3C.

System Interface: The Vehicle Control Module (VCM) required a CAN Bridge device to communicate with the upgraded pack, ensuring correct State of Charge (SoC) display and charge/discharge management.

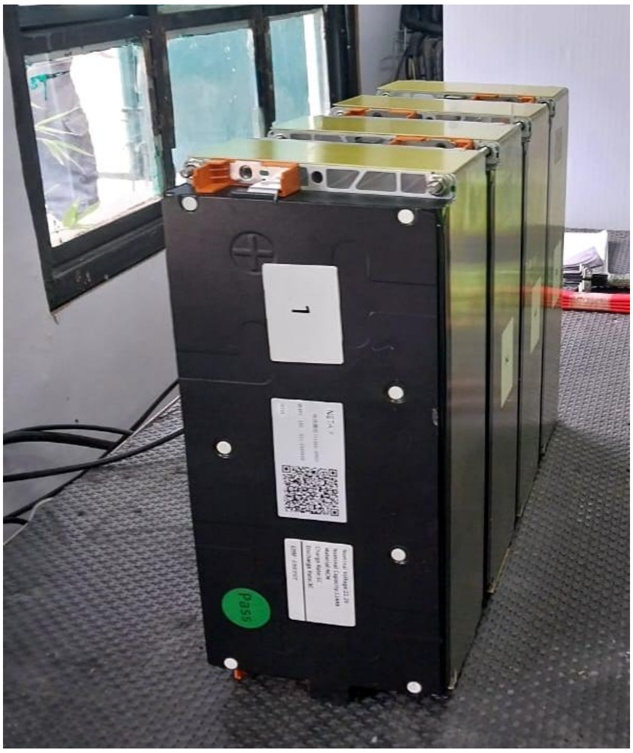

Figure 9 A combination of 4 modules

4.2.3 Removal of the 24 kWh Battery Pack

The vehicle was safely elevated using a hydraulic jack and car stands. High-voltage isolation was performed and verified with insulated tools. The degraded pack was unbolted, disconnected, and lowered using a pallet jack and trolley jack.

The disassembly revealed a battery pack in physically good condition, indicating great battery protection from the physical environment.

Figure 10 Original 24 kWh Battery Removed

4.2.4 Installation of the 40 kWh Pack

The first-tier battery modules were structurally bonded and insulated to ensure mechanical integrity and thermal isolation. Once secured, the second-tier modules were positioned and aligned accordingly.

- Cable and Connectivity: Due to the limited length of OEM-supplied cables, longer cables salvaged from decommissioned packs were repurposed to bridge the rear modules with the service switch and front harness. This ensured reliable connectivity without compromising safety standards.
- Structural Integration: Rear module stabilisation was achieved using brackets and mounts repurposed from an older pack. These components were adapted to maintain structural rigidity and alignment within the enclosure.
- System Integration: High-voltage harnesses, insulation boards, and current/temperature sensors were installed and verified. The Battery Management System (BMS) harness was connected in a strict sequence (LB16 → LB11) to prevent communication faults and ensure proper initialisation.
- Final Assembly: The entire pack was sealed, reinstalled beneath the chassis, and torqued to specification to meet mechanical and safety requirements.

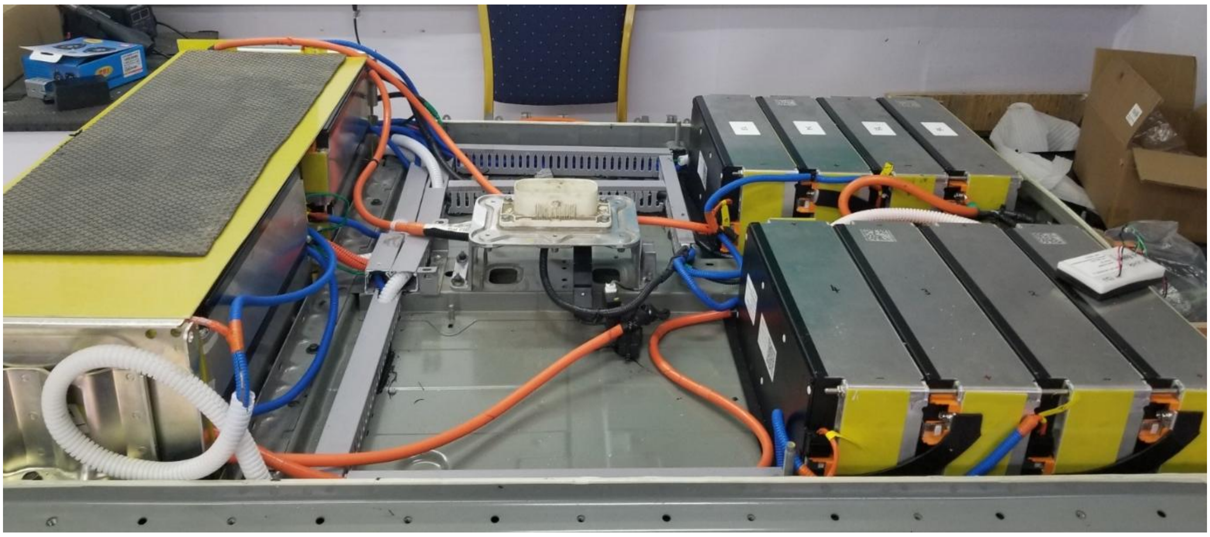

Figure 11 Assembly of the 40 kWh Battery Pack

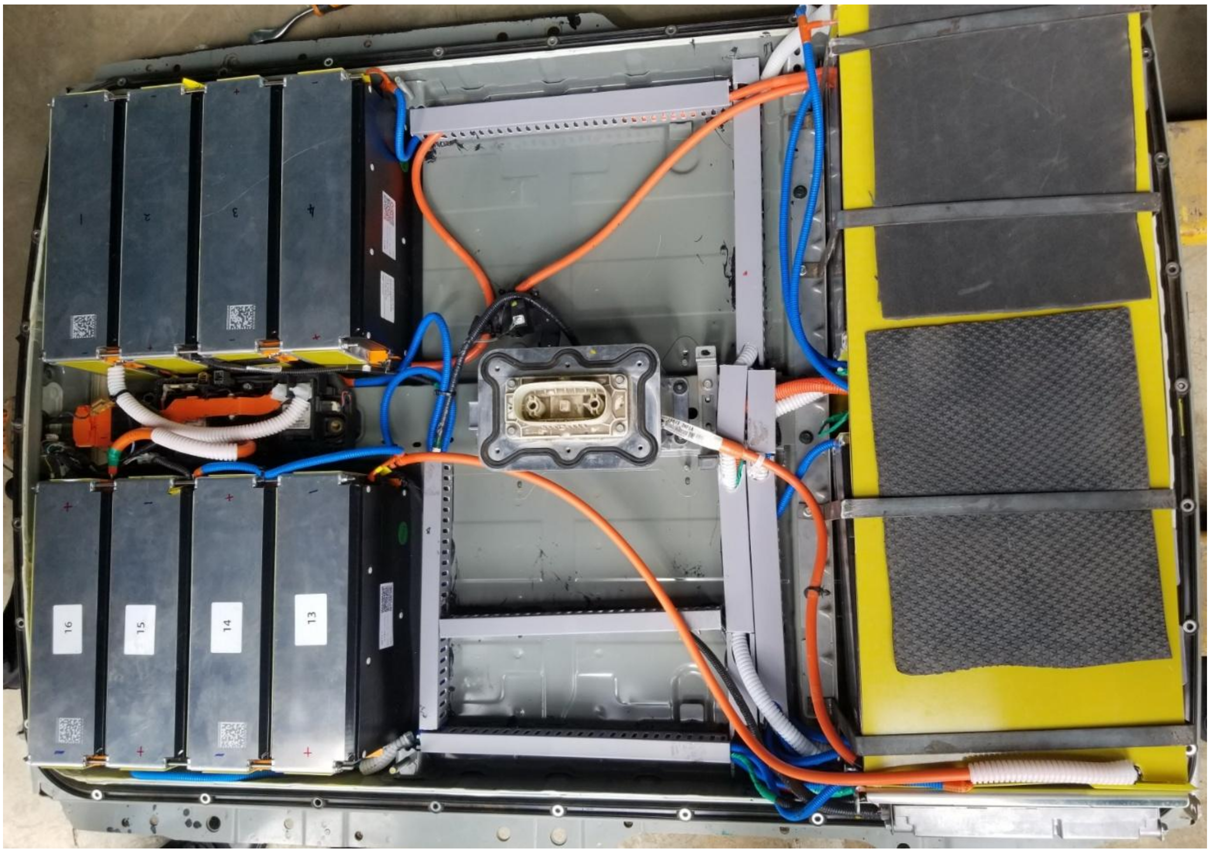

Figure 12 Final Assembled Battery Pack with Rear Modules Secure

4.3 Post-Installation Testing

4.3.1 Electrical Testing

Before final sealing and reinstallation of the battery pack into the vehicle chassis, a comprehensive voltage verification was conducted to ensure system integrity and compliance with design specifications. As shown in the image below, the measured pack voltage registered at 388 V—precisely matching the nominal voltage expected by the OEM for the 40-kWh configuration. This alignment confirms that all modules were correctly connected, balanced, and operating within safe voltage thresholds, thereby validating readiness for integration and operational deployment.

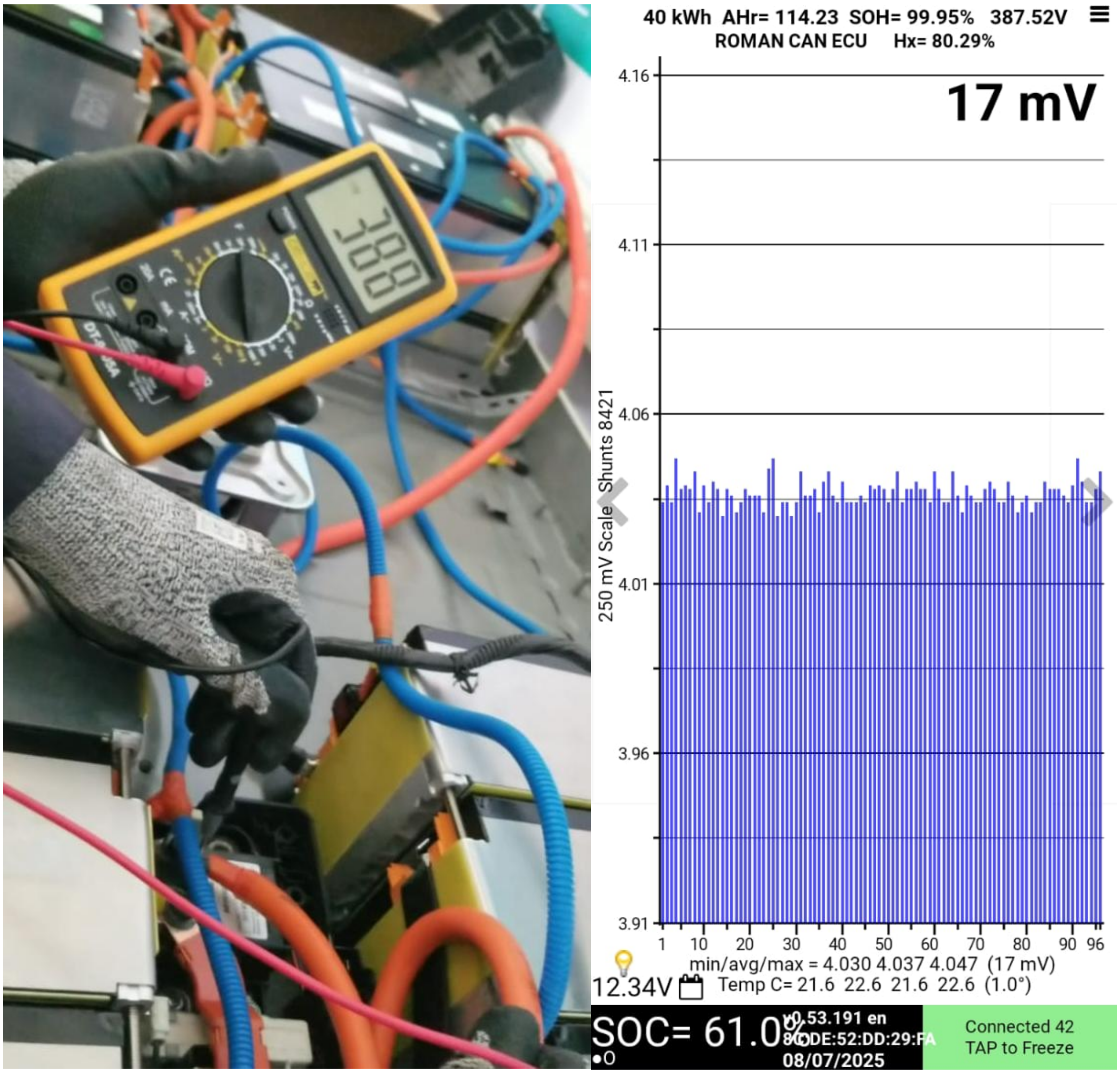

Figure 13 40 kWh Leaf Spy Diagnostic Summary

To supplement the physical verification process, a Leaf Spy diagnostic test was conducted to extract detailed battery health metrics and validate system performance. The test revealed a State of Health (SoH) of 99.95%, indicating optimal cell integrity. The recorded pack voltage was 387.52 V, closely aligned with nominal specifications and consistent with prior manual measurements using a multimeter. Additional diagnostic parameters included:

- Hx Value: 80.29%, reflecting the internal resistance profile and indicative of robust charge acceptance and discharge efficiency.
- Available Capacity: 114.23 Ah, confirming the high-voltage battery's effective energy storage capability and alignment with the expected range for a 40-kWh configuration.

These results collectively affirm the pack's readiness for operational deployment and validate its suitability for reintegration into the vehicle system.

4.3.2 Test Results

To facilitate enhanced communication between the upgraded high-voltage battery pack and the vehicle's onboard systems, a Controller Area Network (CAN) bridge was installed on the Nissan Leaf. This intermediary device enables real-time data translation between the battery management system (BMS) and the vehicle's electronic control units (ECUs), thereby unlocking advanced customisation and upgrade functionalities. Key operational enhancements enabled by the CAN bridge include:

- Accurate Battery Capacity Display: Real-time SoC and capacity metrics are now reflected on both the dashboard and Leaf Spy interface, improving diagnostic transparency.
- Battery Saver Modes: Selective activation of energy conservation protocols to extend pack longevity.
- Charging Speed Modulation: Dynamic control over charge rates to optimise thermal performance and grid compatibility.
- Bypass of OEM Part Pairing Restrictions: Enables seamless integration of non-original battery modules without triggering system faults or compatibility errors.

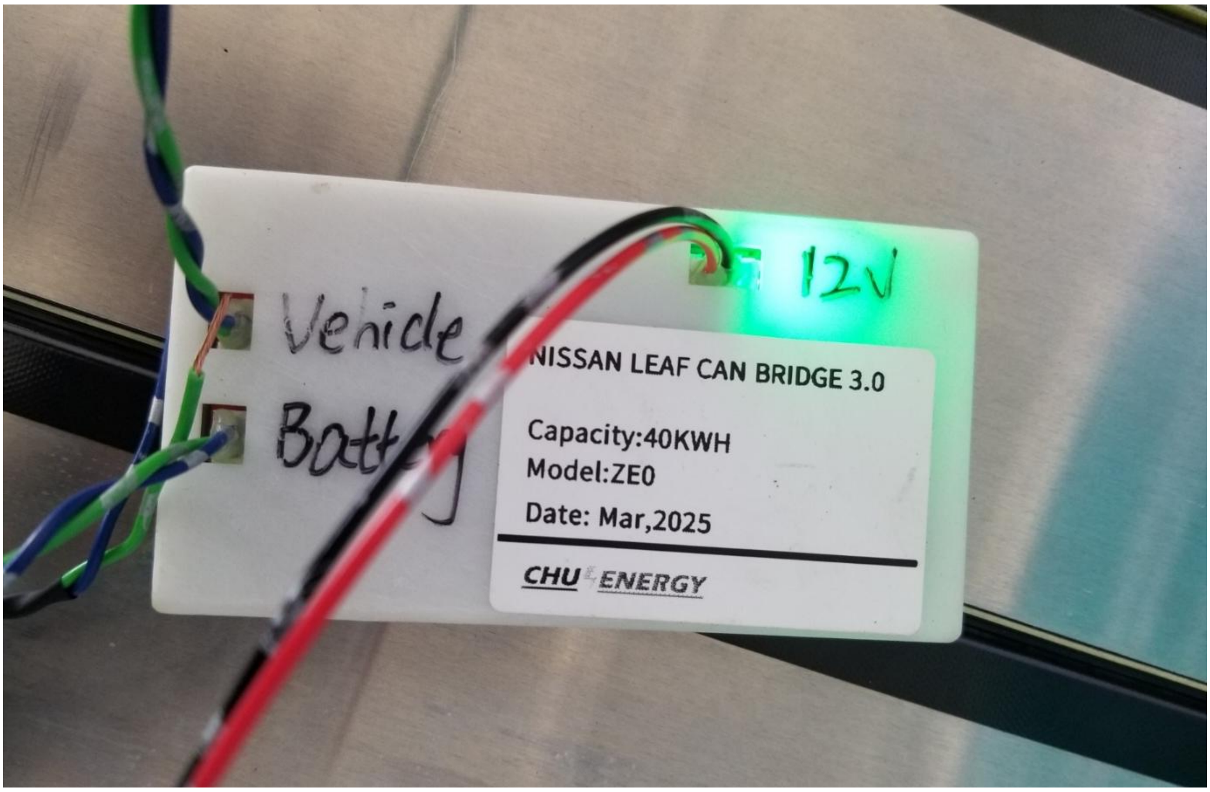

Figure 14 CAN Bridge Setup

Following the integration, the dashboard range display increased to 318 km, a substantial improvement from the prior 40 km estimates on a single charge. This enhancement reflects both the upgraded battery capacity and the recalibrated range estimation algorithm enabled by the CAN bridge.

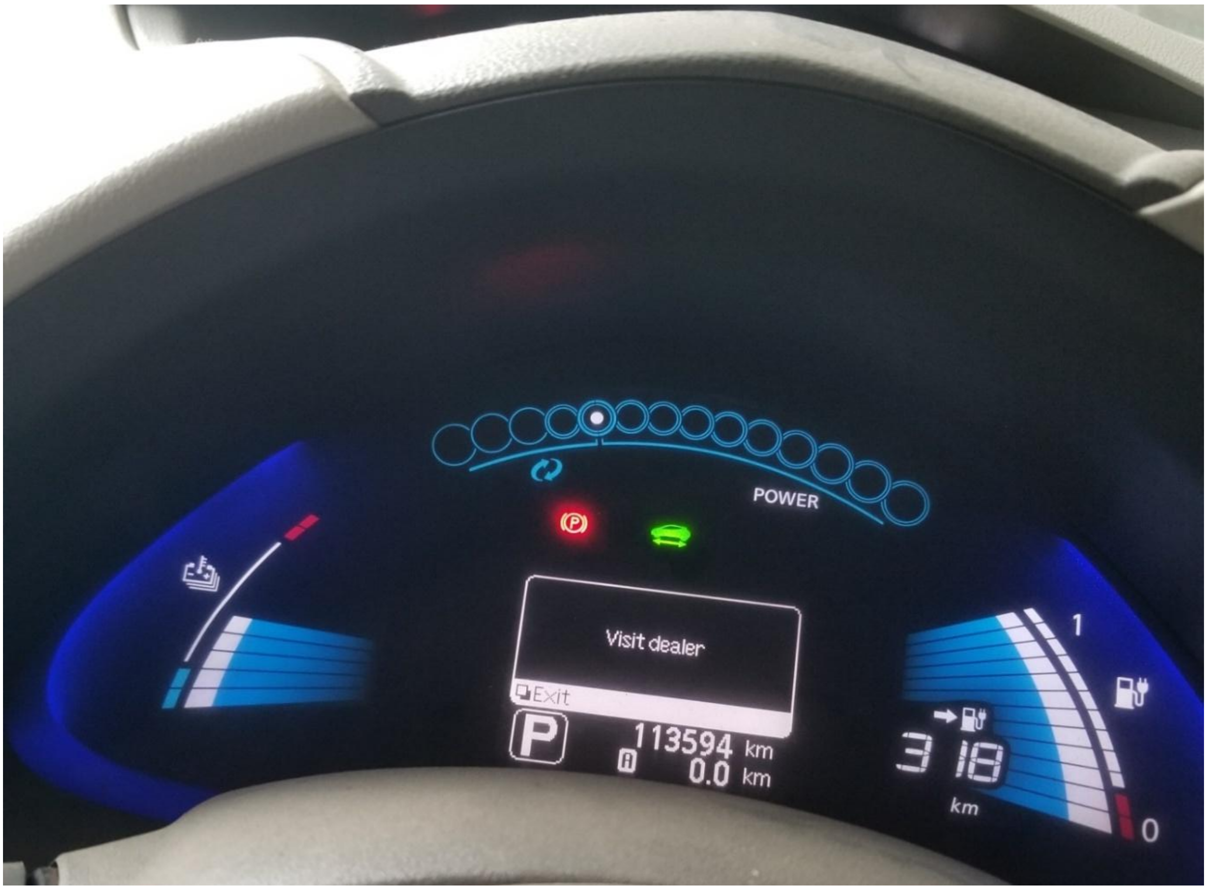

Figure 15 Dashboard Range Display of the 40 kWh Battery Pack

The pilot demonstrated that EV battery replacement is both technically viable and transformative in performance outcomes. Adaptive use of local materials and technical innovation were critical in overcoming manufacturer and logistical gaps. For Kenya's transition to electric mobility, both replacement and repair frameworks must be developed in parallel, supported by training, standardisation, and supply-chain strengthening.

4.4 Technical and Operational Challenges in EV Battery Retrofit

Despite the successful upgrade from a 24 kWh to a 40-kWh battery pack, the retrofit process revealed several critical challenges that underscore the need for standardised procedures, specialised tooling, and enhanced technician training. These challenges spanned mechanical handling, component compatibility, documentation gaps, and electrical safety risks.

- Mechanical Handling and Safety
  The upgraded 40 kWh battery pack and the 24-kWh battery pack weigh approximately 300 kg, presenting significant handling risks. Without appropriate lifting equipment, technicians faced difficulty in safely manoeuvring and positioning the pack during

disassembly and reinstallation. This highlights the necessity for specialised lifting tools and multi-person handling protocols to ensure safety and precision.

- Documentation and Technical Guidance
  The absence of a comprehensive installation manual for the 40-kWh pack created ambiguity in module fitting, BMS harness sequencing, and verification procedures. This gap necessitated on-the-spot engineering judgment, increasing the risk of misconfiguration and communication faults. It also emphasised the need for localised retrofit protocols and technical training programs tailored to regional technician capabilities.
- Skilled Personnel Shortage
  The retrofit process required an advanced understanding of high-voltage systems, CAN communication, and thermal/electrical integration. A shortage of technicians with this expertise delayed progress and increased reliance on trial-and-error methods. This underscores the importance of capacity building initiatives and certification pathways to develop a skilled workforce capable of executing complex EV conversions.
- Electrical Integration and Component Failure
  Upon initial power-up of the new battery pack, the pre-charge resistor failed due to excessive inrush current. The 40-kWh pack's higher capacity introduced a surge that exceeded the original resistor's rating. The pre-charge resistor plays a critical role in gradually charging input capacitors before the main contactor closes. Its failure risked damage to relays and capacitors, necessitating the installation of a higher-rated resistor capable of managing elevated current levels.

Table 3 Categorised Challenges and Recommendations

Challenge	Description	Impact	Recommended Mitigation
Heavy Battery Pack	The 24 kWh and 40 kWh packs weigh ~300 kg; difficult to lift manually	Safety risks, potential damage during handling	Procure hydraulic lifts, hoists, and multi-point support frames; enforce multi-technician handling protocols
Missing Rear Module Brackets	No OEM brackets included for securing rear modules	Structural instability, vibration risks	Fabricate custom brackets or adapt mounts from decommissioned packs; standardise retrofit bracket kits
Short OEM Cables	Supplied cables are insufficient for rear module connectivity	Incomplete electrical integration, risk of loose connections	Use salvaged longer cables or specify custom cable lengths in retrofit kits

Incomplete Technical Manual	Lack of guidance on module layout, BMS sequence, and verification steps	Increased error risk, reliance on trial-and-error	Develop localised retrofit manuals; integrate visual schematics and step-by-step procedures
Skilled Personnel Shortage	Limited availability of technicians trained in HV systems and EV retrofits	Delays, increased error rates	Launch targeted training programs; establish certification pathways with local partners.
Pre-charge Resistor Failure	The original resistor is unable to handle the inrush current from the 40-kWh pack	Component damage, system failure	Install higher-rated pre-charge resistors; include surge analysis in retrofit design

4.5 Recommendations for Scaling Battery Replacement in Kenya

Developing Technical Capacity

- Establish accredited training and certification programs for technicians on high-voltage battery replacement, repair, and safety protocols.
- Create technical manuals and SOPs tailored to Kenya's context.

Strengthening Supply Chains

- Partner with OEM and local partners to ensure and develop a local battery collection and repurposing system to harvest usable modules from retired packs.

Reduce Costs through Policy Incentives

- Introduce tax rebates or subsidies on replacement packs and certified repairs.
- Support financing models (e.g., buy back) to lower upfront costs for fleet operators.

Promote Repair-First, Replace-When-Necessary

- Encourage workshops to adopt diagnostic-first approaches, where localised repair is attempted before full replacement.
- Support R&D into battery replacement and second-life applications for modules that cannot be reused in vehicles.

Establish Safety and Quality Standards

- Kenya Bureau of Standards (KEBS) should expand EV battery directives to cover replacement protocols, SoH thresholds, and technician accreditation.
- Introduce certification for retrofitted/replaced batteries to assure consumers of safety and performance.

Pilot Scaling through Public and Commercial Fleets

- Start with commercial taxi and fleet operators as demonstration users of replacement and repair services.
- Document outcomes to build confidence among private users.

Create Regional Centres of Excellence

- Position Kenya as a hub for EV battery refurbishment and replacement in East Africa, leveraging regional demand and creating green jobs.

5 Skills and Equipment Assessment

A successful transition to electric mobility requires not only the availability of vehicles and charging infrastructure but also a skilled workforce and adequate diagnostic equipment to support battery management across the value chain. Assessing the current state of skills and tools is therefore critical to understanding Kenya's readiness for large-scale EV adoption and the development of a sustainable battery circular economy. This section examines the capacity of technicians, training institutions, and industry actors, alongside the availability of specialised equipment for diagnostics, repair, repurposing, and recycling. By identifying existing strengths and pinpointing critical gaps, the assessment provides an evidence base for designing targeted interventions in skills development, curriculum design, and equipment provision—ensuring that quality, safety, and sustainability standards are met as the sector scales.

5.1 Skills and Equipment Audit

5.1.1 Skill Development in EV Battery Management

Developing technical skills in EV battery management is a cornerstone for building a safe, reliable, and sustainable e-mobility ecosystem. International experience shows that structured, hands-on training is essential to close capacity gaps in diagnostics, module grading, thermal testing, and battery management systems (BMS). Germany has advanced this agenda through initiatives such as the QualiBattBW project and the EU-funded VOLTAGE Centres of Vocational Excellence, which embed battery training into vocational education and industry partnerships.[12]

Similarly, China has overhauled its vocational system to integrate EV and battery-related curricula, complemented by ILO-supported programs that train educators in emerging technologies.[13] These examples highlight how aligning technical training with industry standards and institutional frameworks can accelerate workforce readiness and ensure that battery repair, repurposing, and recycling practices meet global benchmarks.

5.1.2 Green Skills for EV Transition

The transition to electric mobility is not only a technological shift but also a transformation of skills. Green skills—particularly in EV battery management—are increasingly recognised as the backbone of a sustainable transition. Without a workforce equipped to diagnose, repair, repurpose, and recycle batteries safely, the circular economy potential of EVs cannot be realised.

[12] Skilled Workforce and Education - e-mobil BW GmbH

[13] Lao teachers advance electric vehicle and industrial skills through South-South Cooperation | International Labour Organization

Strategic Importance of Battery Skills

The European Union (EU) has made battery skills a strategic pillar of its industrial policy. Under the Pact for Skills initiative,[14] the Battery European Partnership Association (BEPA) and the Blueprint for Sectoral Cooperation on Skills (2021) identified workforce development as critical to the competitiveness of Europe's battery industry. It is estimated that by 2025, over 800,000 workers across the EU's battery value chain will need to be reskilled or upskilled, including roles in repair, reuse, recycling, and advanced manufacturing.[14]

Training Programs and Curriculum Design

To meet this demand, the European Battery Alliance Academy (EBA Academy),[15] established by EIT InnoEnergy in partnership with the European Commission, delivers targeted battery training programs across member states. The curriculum includes modules on Battery Management Systems (BMS), circular economy principles, second-life safety protocols, and technician-level diagnostics. Courses such as Battery Technician and Battery Management Systems are among the most subscribed, reflecting demand for both entry-level and advanced technical skills.

[14] European Battery Alliance moves ahead: new European Battery Academy launched to boost skills for fast-growing battery ecosystem in Europe - European Commission

[15] The European Institute of Innovation and Technology's European Battery Alliance Academy Surpasses 100 000 Learners Trained to Meet Evolving Industry Needs | EIT

Figure 16 The European Institute of Innovation and Technology

Institutionalisation of Green Skills

Europe's approach demonstrates the importance of embedding green skills development into industrial strategy. The EBA Academy's model creates scalable vocational and higher-education programs in cooperation with universities, training centres, and industry partners. This mirrors broader international practice, with Germany integrating battery curricula into vocational training through the QualiBattBW and VOLTAGE projects, and China reforming its vocational system to create new battery-related majors and technical apprenticeships.

Lessons for Kenya

Kenya can draw valuable lessons from these initiatives. First, developing a national green skills framework focused on EV battery management would align workforce development with the country's energy and mobility strategies. Second, partnerships with TVETs, universities, and private sector actors can help create accredited training programs, ensuring quality and safety. Finally, adopting modular curricula like the EBA Academy's approach would allow Kenya to scale technician capacity quickly while preparing the workforce for emerging opportunities in battery reuse, repurposing, and recycling.

5.1.3 Equipment Evaluation in Repair Facilities

The technical readiness of battery repair and repurposing facilities hinges on access to a full suite of specialised tools spanning diagnostics, safety, mechanical handling, and precision electronics.

For accurate electrical diagnostics, several essential tools are required to evaluate cell health, charge balance, and voltage stability. These tools include a multifunctional meter, an internal resistance tester, and an LCR meter, which measures the inductance (L), capacitance (C), and resistance (R) of electronic components. Additionally, energy and capacity testers contribute to these assessments. The use of both low-voltage and high-voltage Battery Management System (BMS) units, such as the 360V system used in the Nissan Leaf, enables a wide range of diagnostic scenarios and BMS testing. Furthermore, incorporating programmable BMS re-flashing tools could further enhance compatibility assessments.

Mechanically, handling and assembly are well-supported using battery lifts, hydraulic scissor lifts, gantry lifts, and vehicle jacks, ensuring safe and ergonomic access to high-mass battery systems. The pallet system, impact drills, and a 257-piece toolbox cabinet facilitate efficient disassembly and physical inspection workflows.

On the thermal and safety front, multiple thermal imaging cameras are in place to detect cell-level anomalies, while insulation resistance testers, antistatic gloves, fireproof bags, and an explosion-proof cabinet uphold safety protocols critical when dealing with high-voltage lithium-ion batteries. Specialised tools like the spot welders (for cylindrical and prismatic cells), laser welder, and lathe station support cell/module reconfiguration and custom retrofitting—an important capability for second-life deployments.

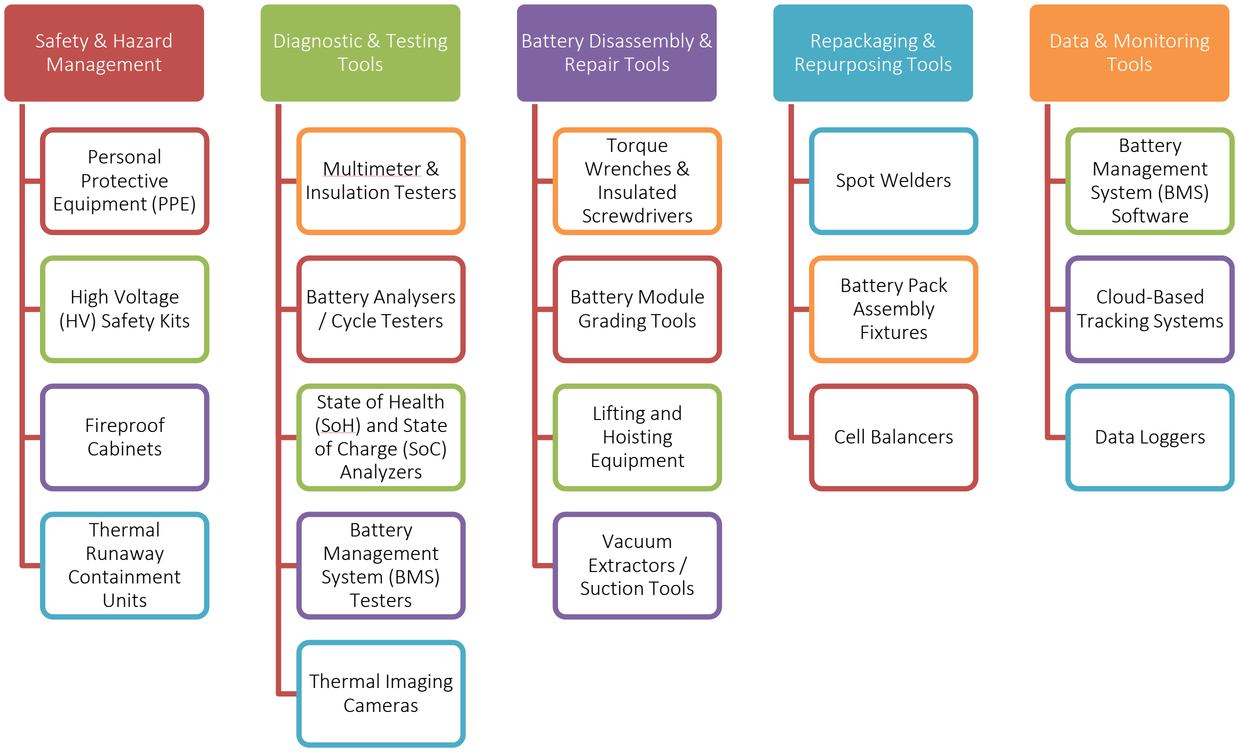

Figure 17 Equipment Required for EV Battery Handling

Despite this well-rounded equipment base, gaps remain. The lack of adjustable programmable BMS diagnostic tools, digital cell monitoring interfaces, and cycling test benches for long-duration stress testing may limit the precision and scalability of repurposing operations. Furthermore, real-time data logging systems and cloud-based battery traceability platforms could improve tracking and circularity compliance.

Overall, the facility demonstrates a strong equipment backbone, with room to expand into data-driven diagnostics, modular test automation, and programmable BMS standardisation.

5.2 Development of Training and Tools

As electric mobility continues to expand in Kenya, increasing attention is being directed toward addressing the skills gap in electric vehicle (EV) handling. Capacity-building initiatives, such as those led by Advanced Mobility, aim to develop structured programs that equip participants with comprehensive technical knowledge and practical competencies in EV technologies. These programs are designed to prepare technicians for the rapid technological transition underway in the automotive industry.

Figure 18 EV Technology Training[16]

Scaling technician capacity in emerging electric mobility markets requires approaches that go beyond conventional training models. One of the most effective strategies is the adoption of Train-the-Trainer (ToT) frameworks. Unlike traditional programs that focus solely on training individual technicians, ToT models prioritise the development of trainers who can replicate knowledge within their own institutions, organisations, or communities. This approach not only accelerates capacity building but also ensures that the knowledge ecosystem can grow sustainably as demand for skilled professionals continues to increase.

[16] ELECTRIC MOBILITY TECHNICAL TRAINING – JAN 2025 | Advanced Mobility

Figure 19 EV Battery Training at Drivelectric

ToT programs address workforce shortages by creating multiplier effects. A single trainer, well-equipped with advanced technical skills and pedagogical techniques, can train dozens of technicians, thereby amplifying the reach of initial training investments. In fast-evolving fields such as electric vehicle maintenance and battery management, this multiplication is critical for meeting the urgent demand for skilled labour. Furthermore, by standardising curriculum delivery and ensuring consistency in content, ToT models help safeguard the quality of training outcomes.

A key feature of effective ToT programs is the provision of up-to-date, hands-on experience. Trainers are not only exposed to advanced technical concepts but also guided on how to transfer these concepts effectively to diverse learners. This dual focus on technical and instructional competencies ensures that knowledge is not only acquired but also disseminated in a way that aligns with industry standards. In the context of electric mobility, such programs can address both the technical requirements of EV systems and the safety protocols necessary for handling high-voltage batteries.

The establishment of a small cohort of certified battery instructors offers a strong foundation for workforce expansion. These instructors can serve as reference points for quality assurance, ensuring that new trainees are guided by professionals who uphold rigorous technical and safety standards. As the cohort grows, the system becomes self-reinforcing: trainers produce more trainers, gradually reducing reliance on external expertise while building local capacity. This model is particularly valuable in countries where EV adoption is accelerating but institutional training frameworks are still nascent.

Ultimately, Train-the-Trainer models provide a scalable and sustainable pathway for developing the human capital required to support electric mobility transitions. By combining technical mastery, curriculum delivery skills, and a multiplier effect, they can enable the rapid growth of a skilled workforce while maintaining high standards of competence and safety.

5.3 Summary Skills Assessment

Recent site visits of local EV battery service providers reveal that Kenya possesses a foundational level of technical capacity for battery diagnostics and repair. However, significant gaps remain in areas such as formal training, standardisation of practices, and access to specialised knowledge. The figure below highlights the state of skills and workforce readiness required for EV battery handling.

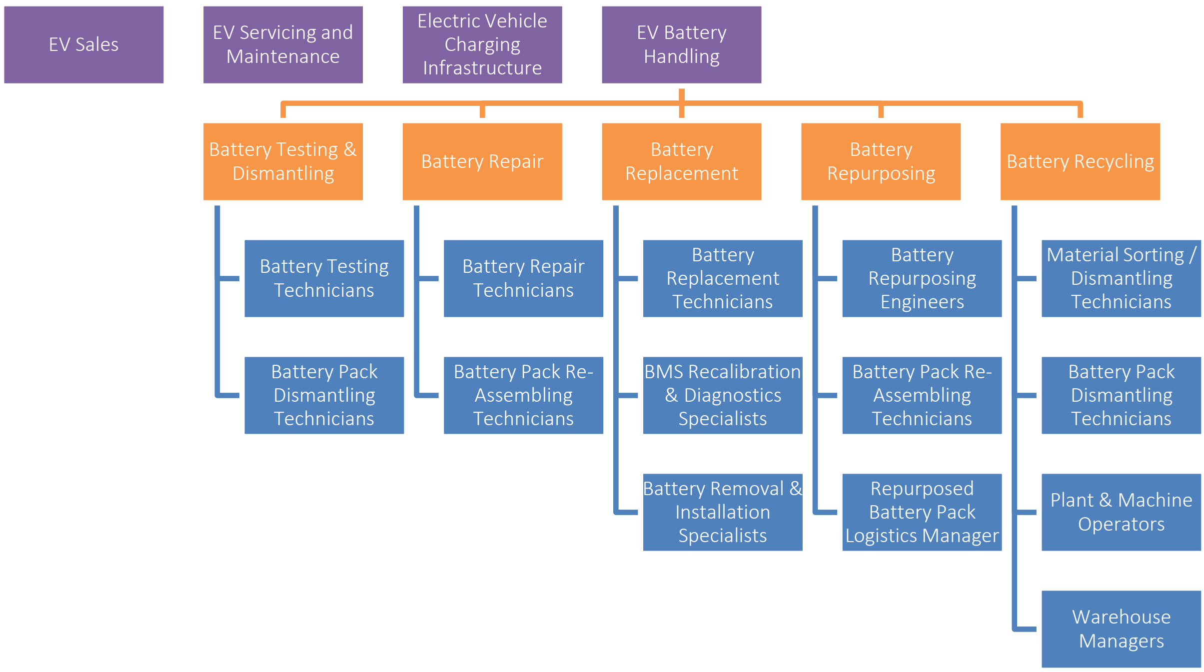

Figure 20 Skills Assessment in EV Battery Ecosystem

Table 4 Summary of Skills Assessment in EV Battery Handling

Domain	Current Status	Gaps and Challenges	Recommended Actions
Technician Availability	A small but growing group of technicians working in battery diagnostics and EV repair.	Most learning is not specialised or on-the-job; few certified trainers or structured pathways.	Launch Train-the-Trainer (ToT) programs and create accredited technician certification.
Training Infrastructure	Limited to private workshops and informal knowledge-sharing.	No nationally recognised curriculum or training standard.	Collaborate with TVETs and industry to develop EV battery-focused training modules.
Skills Coverage	Good baseline in disassembly, voltage testing, and module grading.	Gaps in BMS programming, thermal diagnostics, SoC algorithms, and safety protocols.	Integrate EU-aligned modules on second-life assessment, thermal safety, and BMS testing.
Access to Equipment	Strong base of essential tools; several advanced tools available.	Limited access to programmable BMS tools, cycle testers, and digital analytics.	Subsidise equipment, introduce pooled/shared toolkits for diagnostics.
Safety Knowledge	Basic PPE use observed; fireproofing and electrical safety evident in the workshop.	Inadequate standardised training in HV safety and thermal runaway prevention.	Embed high-voltage safety, fire hazard response, and anti-static protocols into training.
Public Awareness	End-user feedback indicates appreciation of battery reuse benefits.	The public and many stakeholders are unaware of second-life standards and safety.	Integrate awareness campaigns and user guides with technician programs.
Policy and Industry Linkages	Informal partnerships and early-stage collaboration with startups and energy players.	Limited government engagement or strategic skills policy integration.	Align with national energy and skills policies; engage with the EU Pact for Skills and European Battery Alliance (EBA).

The assessment highlights that Kenya has made important early steps in developing capacity for EV battery handling, with around 170 technicians trained in electric vehicles.[16] This still presents a small but growing pool of technicians and a foundation of basic diagnostic and repair skills. However, much of this expertise remains unspecialised, with significant gaps in structured training, advanced diagnostics, access to specialised equipment, and high-voltage safety knowledge. Public awareness of second-life applications and policy integration also remains limited, leaving the ecosystem fragmented.

To bridge these gaps, Kenya should prioritise the development of accredited training pathways, strengthen safety and technical standards, and improve access to advanced tools. Equally critical will be aligning these efforts with national skills and energy policies while raising public awareness. Addressing these areas will not only enhance workforce readiness but also position Kenya to build a robust and sustainable EV battery circularity framework that supports the country's broader e-mobility transition.

6 Policy Recommendations

6.1 Policy Recommendations and Guidelines

6.1.1 Battery degradation (performance & transparency)

Based on the UN Global Technical Regulation (GTR) on In-Vehicle Battery Durability for Electrified Vehicles, the following recommendations should be adopted:

Adopt Minimum Performance Requirements (MPR) for Battery Durability

- **Mandate SOCE thresholds**: Require electric vehicles (EVs) to retain at least 80% of certified usable battery energy State of Certified Energy (SOCE) after 5 years or 100,000 km, and 70% after 8 years or 160,000 km.
- **Optional SOCR monitoring**: Begin with SOCE-based MPRs and monitor State of Certified Range (SOCR) (also described as range retention) for future inclusion once data and infrastructure mature.

Establish In-Use Verification Protocols

- **Part A (Monitor Accuracy)**: Require manufacturers to verify the accuracy of onboard SOCE monitors using certified test procedures. The Kenya Bureau of Standards (KEBS) can adopt a statistical sampling method to validate and monitor accuracy.

- **Part B (Battery Durability)**: Collect annual SOCE data from a representative sample of vehicles to ensure compliance with MPRs. For fleets under 500 vehicles, allow exclusion of up to 5% of outlier data with justification.

Mandate Onboard Battery Health Monitoring

- Require all PEVs and OVC-HEVs sold in Kenya to include SOCE monitors with:
  - 1% resolution
  - Accessibility via OBD port and optionally via mobile apps or dashboard display
  - Consumer-facing battery health indicators to support second-hand EV market transparency

Define Battery Durability Families for Compliance

- Group vehicles into durability families based on battery type, BMS configuration, thermal management, and charging power. This enables efficient compliance testing and data aggregation.

Incentivise Declared Performance Requirements (DPR)

- Allow manufacturers to declare higher durability targets (e.g., 85% SOCE at 5 years) to differentiate premium products.
- Use DPRs to guide green procurement policies for public EV fleets.

Develop a National Battery Durability Registry

- Create a centralised database to track SOCE values, warranty claims, and repair statistics across EV models.
- Use this data to refine MPRs and inform future amendments to Kenya's EV regulations.

Phase-In Regulation with Stakeholder Engagement

- Begin with voluntary compliance and pilot programs in collaboration with manufacturers and fleet operators.
- Transition to mandatory standards within 3–5 years, aligned with Kenya's EV roadmap and infrastructure readiness.

Additionally.

- **Require an EU-style digital battery passport for EV packs by a set date (e.g., 2028),** including unique ID, chemistry, capacity, repairability info, SoH, and EPR owner—compatible with the EU format to preserve export/second-hand market value.
- **Thermal management & fast-charging guidance**: publish operating envelopes (temperature/SOC windows) as national standards; require BMS to log DC fast-charge usage to inform warranties and second-life decisions (data fields stored in the passport). Align with durability verification under UN GTR.

6.1.2 Battery repair & replacement (safety, circularity, supply chains)

- **Extended Producer Responsibility (EPR) with local take-back**: work with international OEMs/importers to work with local partners to support the collection, testing, repair, repurposing and recycling networks nationwide.
- **Authorise certified repair & remanufacture**: create a licensing scheme for high-voltage (HV) battery repair centres (module-level repair, pack refurbishment) with auditable SOPs.[17]
- **Standardise retrofit/upsize rules**: permit safe, documented pack replacements (e.g., upgrade of 24 kWh to 40 kWh) if installers meet accredited procedures (isolation tests, pre-charge, CAN-bridge validation) and update the battery passport accordingly.
- **Second-life enablement**: legally recognise reuse of retired EV packs in stationary storage (ESS) with performance/safety certification taking cues from South Korea's reuse framework—and set minimum test protocols before grid connection.
- **Minimum recycled-content & recycling-efficiency glidepath**: set targets (e.g., cobalt/nickel/lithium recovery and recycled content in new batteries) for setting up recycling plant and material recovery, while allowing compliance via partnerships with regional recyclers.

[17] Regulation (EU) 2023/ of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC

6.1.3 Customer perception (trust, costs, end-of-life)

- **Right-to-know: clear warranties and SoH at point of sale**: require plain-language warranty statements tied to durability standards and SoH disclosures (new and used EVs). UN GTR metrics become the common language for consumers.
- **Total-cost-of-ownership labelling**: publish standardised TCO labels that factor expected degradation and replacement options; align incentives with durable batteries.
- **Visible take-back & recycling options**: EPR operators must provide a public locator for drop-off/repair, and annual performance reports.
- **Passport-backed second-life certificates**: when EV packs are repurposed, issue a standardised "second-life performance certificate" (capacity, impedance, cycles) so consumers can trust ESS products; align with EU passport data fields.

6.1.4 Skills & workforce (training, certification, equipment)

- **National HV Battery Skills Framework and Training of Trainers (ToT)**: build a Train-the-Trainer pipeline through TVETs and engineering faculties and require certification for HV technicians (levels for diagnosis, repair, pack integration, and repurposing).
- **Facility accreditation & audit**: codify equipment and safety minimums (insulation resistance testing, isolation monitoring, thermal imaging, fire suppression, data logging) for any shop handling EV packs.
- **Data & traceability upskilling**: require all accredited facilities to upload battery interventions (repair, module swap, repurpose) to the passport registry.

6.1.5 Cross-cutting enablers

- **Harmonise with global durability & market rules** so Kenyan EVs and batteries remain tradable: adopt UN GTR No. 22; recognise EU battery passports.
- **Targets & timelines** (illustrative, align to Kenya's roadmap and grid realities):
  - 2026: adopt UN GTR No. 22; launch national battery registry.
  - 2027–2028: pilot digital battery passports for all traction batteries placed on the market and ensuring that EPR networks are operational in all counties.
  - 2028: second-life certification scheme in force.

7 Conclusion and Future Work

Kenya's transition to electric mobility offers an important opportunity to achieve climate mitigation, reduce oil import dependence, and build new green industries. However, the sustainability of this transition depends on how effectively the country manages EV batteries across their lifecycle—from import and use, to repair, repurpose, and end-of-life recycling. Lessons from the EU's comprehensive Battery Regulation, China's traceability and take-back systems, and South Korea's second-life battery frameworks demonstrate that well-designed policies can simultaneously protect consumers, reduce environmental risks, and create economic value.

For Kenya, aligning with international best practices while tailoring them to local conditions will be essential. Durability standards, digital tracking systems, and accredited repair facilities can ensure quality and safety. At the same time, training programs will be crucial to develop a skilled workforce capable of safely handling high-voltage systems and leading innovation in second-life applications.

Future work should focus on four priority areas:

1. Battery Passport Design and Implementation
    - Develop a national digital battery passport learning from the EU framework to track state-of-health, composition, repair, and ownership history.
    - Pilot the system with major importers and public transport fleets before scaling nationally.
2. Training and Curriculum Development
    - Design standardised curricula for EV battery diagnostics, repair, replacement and repurposing, embedded into TVET and university programs.
    - Establish Train-the-Trainer models to quickly build a network of certified instructors and technicians across the country.
3. Research and Monitoring
    - Create a National EV Battery Observatory to collect real-world data on degradation, second-life applications, and recycling efficiency.
    - Use the data to refine standards, warranties, and consumer protection frameworks continuously.
4. Consumer Awareness and Engagement
    - Launch targeted campaigns to educate consumers on battery lifespan, warranties, repair and replacement options, and safe disposal pathways.
    - Develop a certification or "second-life quality label" for repurposed batteries to improve public trust in reused energy systems.