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Programme : MSc – Automotive Engineering

Module : Research Methods

Module code: ACHA7027

Assignment Title: Research Proposal & Presentation

**Research Proposal: TECHNICAL EVALUATION OF SECOND-LIFE
EV BATTERIES FOR STATIONARY ENERGY STORAGE
APPLICATIONS**

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Abstract

The rapid global adoption of electric vehicles (EVs) has led to a significant increase in end-of-life lithium-ion batteries, which typically retain 70–80% of their original capacity. This presents both an environmental challenge and an opportunity for second-life applications in stationary energy storage. This research proposes a systematic technical evaluation of the feasibility of repurposing EV batteries for such applications. The study critically examines battery degradation mechanisms, compares state-of-health (SoH) estimation techniques, and evaluates application-specific feasibility and thermal safety risks. A mixed-methods approach is employed, combining systematic literature review, analysis of published degradation datasets, and structured case study evaluation. The research aims to develop a five-stage evaluation framework addressing the current lack of integrated assessment methodologies in both academic and industrial practice.

Introduction

Electric vehicles (EVs) are becoming a key component of decarbonization strategies in both personal and commercial mobility due to the global shift towards sustainable transportation. Over the past ten years, sales have increased dramatically thanks to advancements in battery technology, falling costs, and tightening regulations in North America, China, and Europe. Global EV stock exceeded 16 million in 2021, according to the International Energy Agency (IEA, 2022), and this number is predicted to rise sharply under net-zero promises. A lithium-ion battery pack, a complex electrochemical device that stores and provides traction energy, lies at the heart of every electric vehicle. When the State of Health (SoH) deteriorates to about 70–80% of rated capacity, these packs are typically removed from vehicular operation. At this point, reduced range and impaired performance render prolonged EV usage unfeasible. Crucially, though, significant capacity is still available, thus this retirement barrier does not signify the end of useful electrochemical life. Repurposing is theoretically possible because the battery pack design, which includes cells, cooling systems, BMS, and structural components, maintains its physical integrity during retirement, as seen in Figure 1.

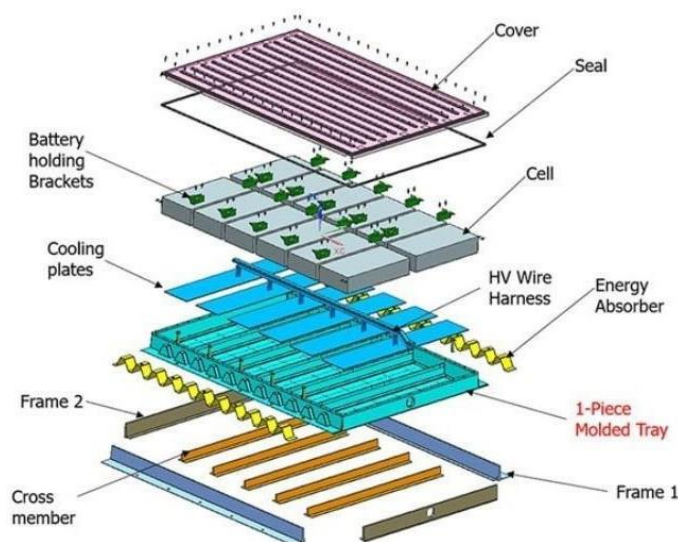


Figure 1: Exploded view of an EV battery pack showing key structural and electrochemical components. At retirement, this assembly retains 70–80% of its original capacity. (Source: Adapted from automotive engineering literature)

The increasing number of retired packs poses strong business potential as well as an environmental challenge. Early recycling requires energy-intensive processes and forfeits significant residual energy storage value. On the other hand, second-life redeployment in stationary storage can prolong productive lifespan, postpone recycling, and provide affordable storage capacity to facilitate the integration of renewable energy sources. To provide a structured evaluation methodology that is currently lacking in both academic literature and industrial practice, this research proposal provides a methodical inquiry into the technological viability of second-life EV batteries. Even though battery degradation, state-of-health estimates, and second-life applications have been extensively studied, current research is still dispersed and mostly focuses on these areas separately. This research addresses this gap by developing a structured and evidence-based evaluation framework that integrates technical performance, safety considerations, and application-specific feasibility into a unified assessment methodology.

Background and Context

The EV Battery Lifecycle and Second-Life Concept

The entire lifetime of a second-life EV battery system is depicted in Figure 2, which includes the extraction of raw materials and battery production, EV service and retirement, stationary storage deployment, and end-of-life treatment (recycling, landfill, or incineration). Understanding the opportunities and responsibilities related to using second-life batteries requires a lifecycle perspective. By prolonging the battery's usable life prior to final disposal, second-life deployment lowers the overall environmental burden per unit of stored energy, as shown by the flow of resources, energy, emissions, and waste products at each stage.

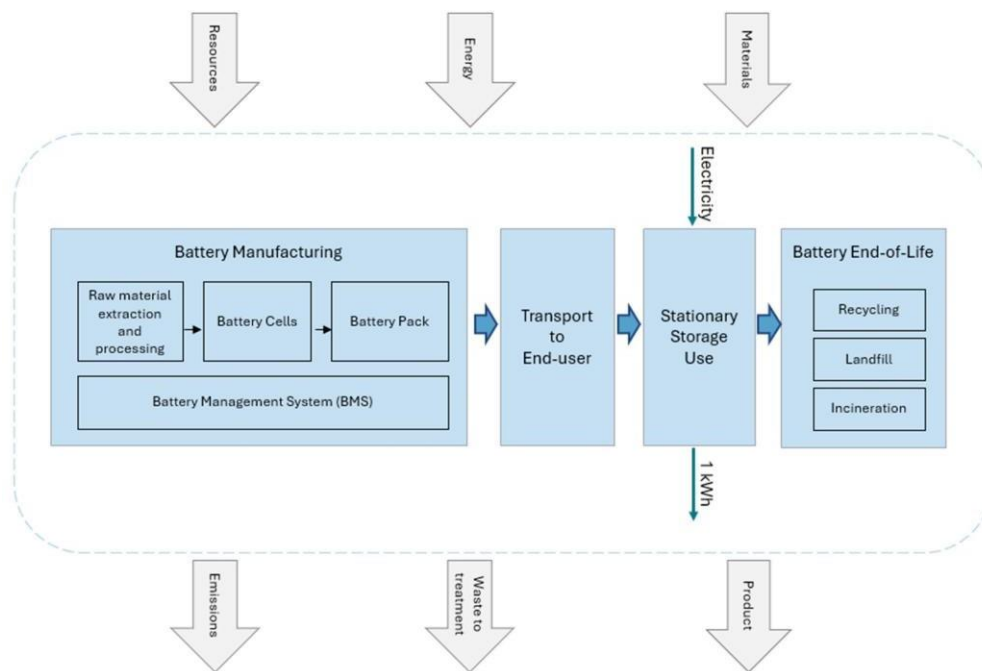


Figure 2: Full lifecycle of a second-life EV battery system, from manufacturing through stationary storage use to end-of-life treatment. (Source: Adapted from lifecycle analysis literature)

However, it's crucial to remember that second-life use does not always have a positive impact on the environment. According to Casals et al. (2017), the effectiveness of the repurposing process itself has a significant impact on the net lifecycle impact. The environmental benefit may be diminished if repurposing necessitates significant disassembly, retesting, and component replacement due to the accompanying energy and material costs. The main result of this research is a simplified, technically sound evaluation framework, which is directly motivated by this discovery.

Real-World Second-Life Deployment

Numerous significant projects have shown that second-life EV batteries are commercially viable. Used Nissan LEAF battery packs, particularly the 40 kWh model, are repurposed into containerized stationary storage systems under the Nissan xStorage program, which is seen in Figure 3. To support batteries of different types and SoH, this architecture uses galvanically isolated DC-DC modules that are connected to an AC/DC converter for grid interface. Real-time monitoring and dispatch control are made possible by Energy

Management System (EMS) communication via CAN/Modbus, while the thermal and safety needs of older cells are met by specialized heating/cooling and fire protection systems.

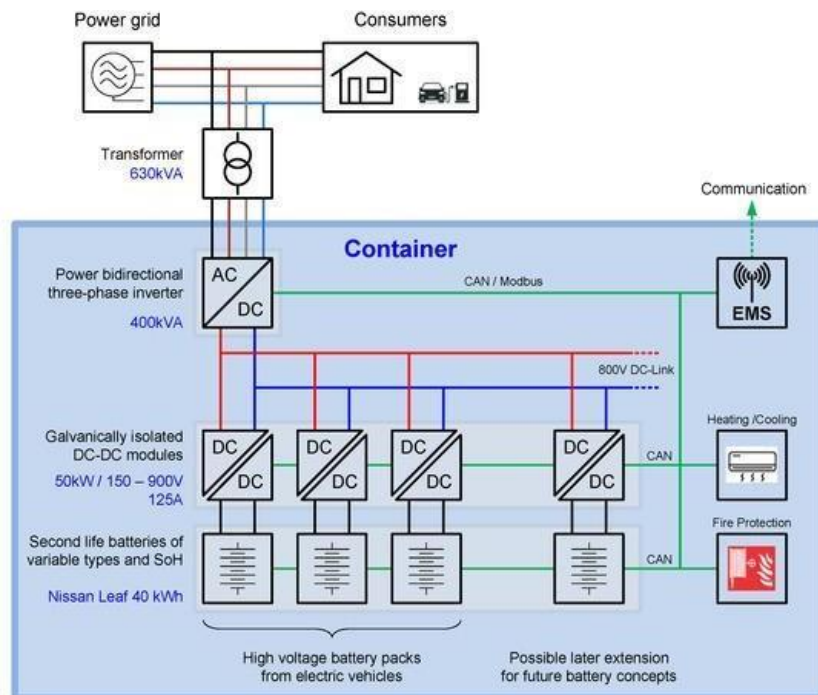


Figure 3: Nissan xStorage second-life battery system architecture, showing DC-DC module interface for batteries of variable SoH, grid connection, and energy management system. (Source: Nissan/xStorage technical documentation)

Using over 250 of these second-life packs, the Johan Cruyff Arena installation in Amsterdam offers large-scale grid stability and solar energy buffering services. The technical architecture depicted in Figure 3 is instructive: the SoH variability seen in second-life packs directly results in the need for individual DC-DC conversion at the battery module level. In comparison to fresh battery installations, this design increases system complexity and expense, highlighting the financial significance of precise SoH assessment to reduce the range of variability within a deployed system.

Per-module DC-DC converters are used in the xStorage architecture to provide varied SoH exemplifies a basic trade-off in the design of second-life systems: higher SoH heterogeneity necessitates more complex (and expensive) power electronics. The evaluation approach suggested by this study attempts to formalize this relationship, which directly connects the quality of upstream battery screening to downstream system cost.

Research Problem and Gap

Widespread commercial use of second-life EV batteries is still limited by several interconnected and unsolved technical issues, despite the obvious possibility. These are basic knowledge and standardization gaps that presently impede the development of an open, dependable, and scalable second-life battery industry. They are not only incremental engineering issues.

Degradation Variability and Its Consequences

Given variations in vehicle make and model, battery chemistry, charging history, thermal management quality, operating temperature, and overall cycle count, EV battery packs show very heterogeneous degradation upon retirement. This heterogeneity produces qualitatively distinct residual states that call for essentially diverse second-life management techniques; it is not just a question of degree.

Cell-level heterogeneity brought on by manufacturing tolerances and thermal gradients can produce internal imbalances within a single pack that are undetectable at the pack level but might hasten deterioration or pose safety hazards during second-life cycling. The industry's current screening methods, which mostly use pack-level SoH testing, are insufficient to capture this internal variation. This gap will continue to prevent safe and dependable second-life deployment until cell-level characterization techniques are commercially feasible on a scale.

The crucial concern is whether deterioration variability can be well defined to enable safe deployment at a reasonable cost, rather than just whether it exists. In addition to proposing a tiered approach that calibrates characterization depth to application risk level—lower-risk applications, like grid buffering, may tolerate higher residual uncertainty than higher-risk applications, like residential storage in occupied buildings—this study will make the case that current screening techniques are necessary but insufficient.

SoH Estimation: A Multi-Method Problem with No Universal Solution

For second-life deployment to be both safe and cost-effective, accurate SoH assessment is necessary. However, there isn't currently a single estimation technique that meets every need in the variety of real-world scenarios. This limitation represents basic trade-offs between operational realities, financial constraints, and physical measuring principles; it cannot be overcome by incrementally improving any one technique.

Three main strategies are identified in the literature, each with unique advantages and disadvantages:

- **Coulomb counting:** This method is inexpensive and easy to use, but it accumulates sensor errors, is unable to differentiate between degradation modes, and offers no information on internal resistance, which is a crucial factor for evaluating power capabilities in stationary applications.
- **Electrochemical Impedance Spectroscopy (EIS):** The gold standard for diagnostic accuracy, but it is not practical as a universal field-screening tool, especially for high-volume processing, because it requires laboratory equipment, controlled conditions (stable temperature, specific SoC), and trained personnel.
- **Machine Learning (ML):** Excellent predictive accuracy when training data is representative; but, as EV chemistry diversity rises, ML is vulnerable to distribution shifts between training datasets and the diverse population of retired batteries entering the second-life supply chain.

These approaches are complementary tools whose ideal combination depends on application context, risk tolerance, and resource constraints rather than competing

alternatives to be ranked in absolute terms. This is a crucial analytical insight that the literature currently in publication fails to synthesize into practical advice. This study will contend that the most practically sound approach is a hybrid approach that combines ML for remaining usable life prediction, EIS for selecting detailed diagnosis

of borderline cases, and coulomb counting for initial triage. Comparative comparison using published ageing datasets will provide empirical support for this claim. Nevertheless, the majority of current research assesses these techniques in isolation and under controlled circumstances, which restricts their relevance to actual second-life battery systems. This draws attention to an important gap in the literature.

Thermal Safety: A Gap That Existing Standards Do Not Address

The lack of a framework that combines degradation characterization, SoH estimation, thermal safety, and feasibility assessment into a cohesive, repeatable methodology is the biggest obstacle to scalable second-life battery deployment, not a lack of expertise in any one area. Due to the broad variations in industry practices, the market is typified by information asymmetry and uneven quality assurance, which raises buyer risk and limits the growth of liquid secondary battery markets.

Performance standards and safety procedures for second-life stationary applications are not yet specified by the EU Battery Regulation (2023), despite the introduction of battery passport requirements and end-of-life management obligations. For repurposes that spend in thorough evaluation, this regulatory gap exacerbates the technical uncertainty and puts them at a first-mover disadvantage. If consumers are unable to discern between high-quality and low-quality second-life products, they will incur higher expenses without being rewarded by market differentiation.

This study fills the gap between the need for an integrated, systematic evaluation approach that can be used across battery chemistries and application settings and specific technical studies that focus on deterioration, SoH, safety, or feasibility in isolation. Repurposes, integrators, and regulators will receive practical, graded guidance from the framework, filling a gap that has been recognized in the literature and validated by the lack of established industry standards.

Research Aim and Objectives

Research Aim

In order to create a structured, evidence-based evaluation framework for use in industry and academia, a systematic and critical technical evaluation of second-life EV batteries for stationary energy storage will be carried out. This evaluation will incorporate analysis of degradation mechanisms, comparative evaluation of SoH estimation methodologies, thermal safety assessment, and operational feasibility analysis.

Research Objectives

- Objective 1: To evaluate the effects of degradation heterogeneity across battery chemistries and use profiles on the accuracy of second-life SoH prediction by critically analyzing the primary degradation mechanisms affecting EV lithium-ion batteries throughout their operational lifecycle.
- Objective 2: To systematically assess and compare current SoH estimation methods, such as coulomb counting, EIS, and machine learning models, in order to determine their relative accuracy, cost, practical deployability, and suitability for second-life battery qualification. Additionally, to make an argument for the best methodology combination based on the risk profile and application context.
- Objective 3: Using criteria derived from literature evidence and case study analysis, evaluate the technical and financial viability of implementing second-life EV batteries across stationary storage applications, such as renewable energy buffering, grid stabilization, microgrid integration, and residential/commercial storage.
- Objective 4: To propose evidence-based mitigation measures for thermal runaway risk in heterogeneous battery arrays, assess the suitability of current safety standards for aged cell populations, and critically examine thermal safety issues unique to second-life battery systems.
- Objective 5: To combine the results of Objectives 1-4 into a systematic, five-stage technical evaluation framework for second-life EV batteries, offering regulators, system integrators, and battery repurposes a repeatable and useful technique.

Literature Review

EV Battery Degradation Mechanisms

Degradation of lithium-ion batteries results from a complicated interaction between mechanical, thermal, and electrochemical processes. According to Neubauer and Pesaran's (2011) basic analysis, SEI layer growth and electrode structural changes are the main causes of capacity fade and power fade, which are the two main deterioration mechanisms. Figure 4 illustrates how capacity decreases nonlinearly with cycle number, showing a fast fade at first before steadily stabilizing. This trajectory has important ramifications for predicting second-life performance.

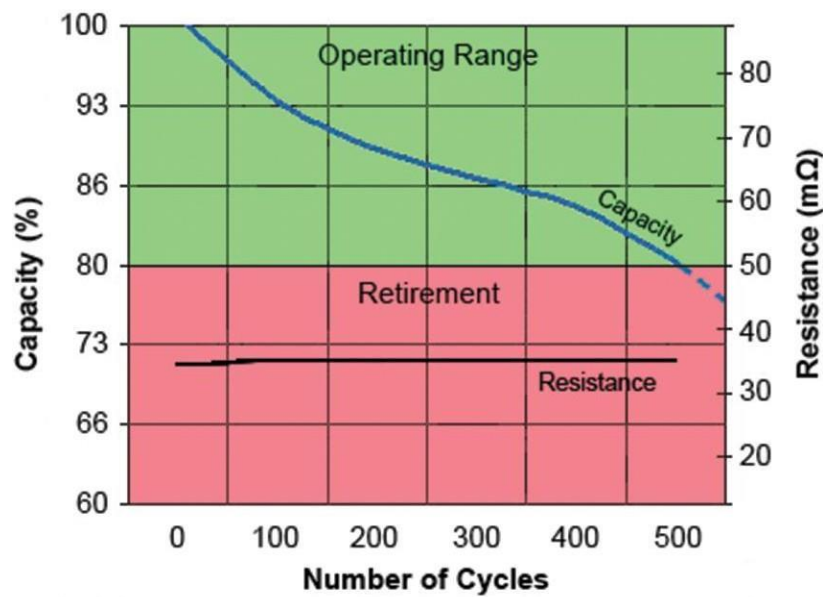


Figure 4: Measured EV battery capacity (%) and internal resistance (mΩ) as a function of cycle number. The 80% SoH threshold marking EV retirement is clearly visible. (Source: Battery degradation study data)

A crucial finding that is frequently overlooked in second-life literature is shown in Figure 4: internal resistance in this example is relatively stable despite capacity declining significantly with cycling. This suggests that, for this chemistry and use profile, second-life batteries may maintain sufficient power capability even at reduced capacity. Martinez-Laserna et al. (2018) showed that batteries from fast-charge-heavy duty cycles show simultaneous and compounded capacity and resistance deterioration, resulting in a fundamentally different residual state at retirement, proving that this relationship is not universal.

This finding highlights a significant flaw in SoH as a single second-life qualification metric. Although both batteries meet the same SoH threshold requirements, a battery at 75% SoH resulting from primarily calendar ageing presents a substantially different second-life proposition than one at 75% SoH originating from intense fast-charge cycling. This supports a multi-parameter qualification method that considers the degradation pathway in addition to end-state SoH. This argument will be incorporated into the construction of the evaluation framework in this study.

The main calendar ageing mechanism is represented by SEI layer development on the graphite anode, which permanently consumes active lithium. According to Casals et al. (2017), compared to vehicles in temperate climates, high-temperature operation accelerates SEI growth by 15–30%, resulting in a systematic geographic bias in the supply chain for second-life batteries. During high-rate charging, lithium plating creates metallic lithium deposits that contribute to capacity loss and, more importantly, to dendritic development and the resulting internal short-circuit danger. Standard non-destructive screening is unable to accurately identify this safety risk. The primary degradation landscape is completed by electrolyte breakdown and electrode structural deterioration, both of which increase internal resistance and decrease energy and power capacity.

State-of-Health Estimation: Critical Comparative Analysis

Objective 2 of this study requires a thorough comparative analysis of SoH estimate techniques. Two opposing strategies are shown in Figures 5 and 6: EIS-combined predictive modelling, a data-driven strategy informed by physics, and coulomb counting, a mathematical integration technique.

Counting Coulomb method

Counting the electrons that enter during charging and leave during discharging.

$$SOC(t) = SOC(t_0) + \frac{1}{C_{rated}} \int_{t_0}^{t_0+\tau} (I_b - I_{loss}) dt$$

$SOC(t_0)$ = Initial charge level

C_{rated} = The battery's rated capacity.

I_b = The current (in amperes) going in or out of the battery.

I_{loss} = The small amount of current lost due to inefficiencies.

Figure 5: Coulomb counting method for battery State of Charge (SoC) estimation. The integral of net current (charge minus loss) over time provides a running estimate of charge state, forming the basis of simple SoH assessment. (Source: Battery estimation methods literature)

Coulomb counting calculates SoC by integrating the net current flow over time in relation to rated capacity, as seen in Figure 5. This technology is the most extensively used option in current practice since it is inexpensive and can be integrated into existing BMS gear. However, its dependability for second-life qualifying is limited by a number of important issues.

First, a precise initial SoC reference point is necessary for coulomb counting. Establishing this reference for old EV batteries that arrive at repurposes with unknown partial-charge histories necessitates a controlled complete charge-discharge cycle, which increases screening time and expense. Second, SoH estimations drift over time due to cumulative current sensor error, especially in older batteries where coulombic efficiency deviates from unity. Third, and perhaps most importantly for second-life applications, coulomb counting measures charge throughput but offers no information about internal resistance, deterioration mode, or remaining useful life—the factors that are most important for forecasting second-life performance and safety.

The primary drawback of coulomb counting is that it measures the incorrect things for second-life qualification reasons rather than producing faulty findings, which can be rather precise under controlled conditions with new sensors. An evaluation of a battery that just considers capacity (by means of coulomb counting) and ignores resistance, thermal properties, and deterioration mode is comparable to evaluating a used car based only on the size of its fuel tank and neglecting engine condition. The evaluation framework's multi-parameter approach will be supported by this analogy.

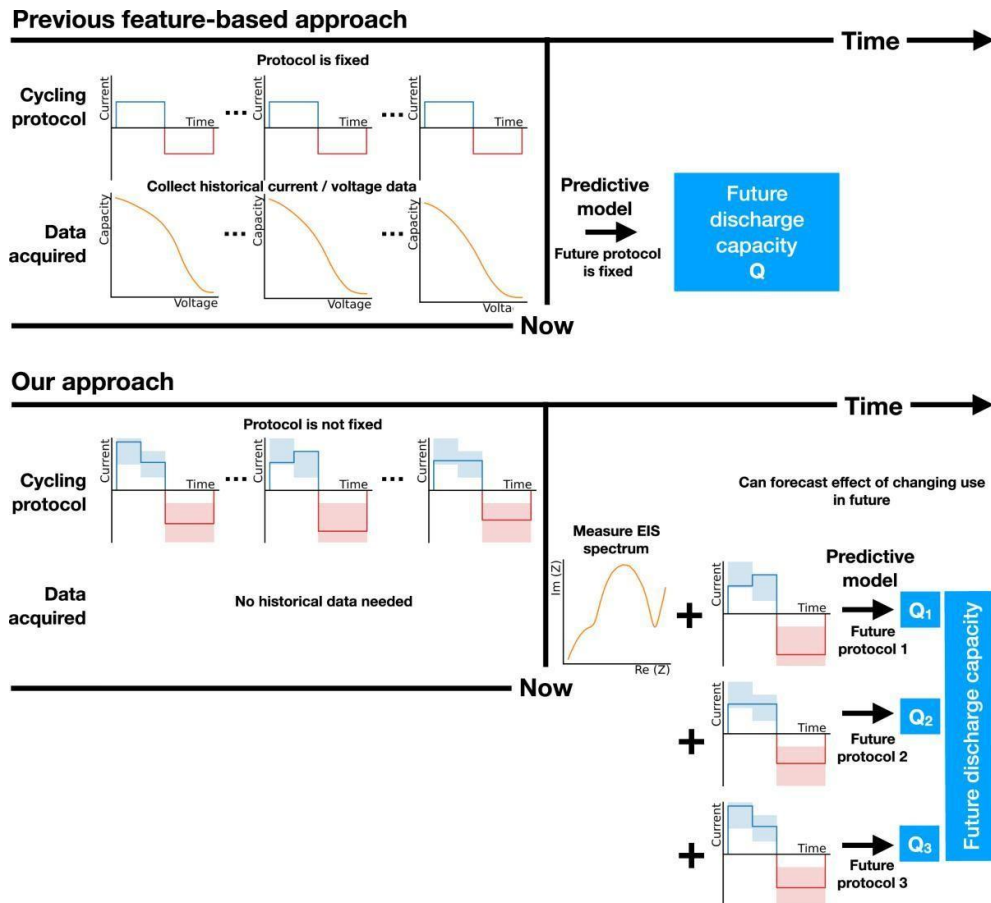


Figure 6: Comparison of feature-based SoH prediction (previous approach, top) with EIS-combined predictive modelling (current approach, bottom). The EIS approach measures impedance spectrum without requiring fixed cycling protocols or historical data, enabling flexible future discharge capacity prediction. (Source: Advanced battery diagnostics research)

An important development in SoH estimation methods is shown in Figure 6. Retired EV batteries that arrive with inadequate usage histories frequently do not meet the requirements of the traditional feature-based solution (upper panel), which calls for a defined cycling protocol and accumulated historical current/voltage data. This restriction is overcome by the EIS-combined technique (bottom panel), which measures the electrochemical impedance spectrum directly without the need for past data or a set protocol. Because battery histories are often incorrect or partial, it is especially appealing for second-life screening.

Compared to single-protocol SoC-based methods, the EIS technique depicted in Figure 6 can anticipate future discharge capacity (Q_1 , Q_2 , and Q_3) under multiple future operating protocols simultaneously, offering richer information for second-life application matching. This capability does come with a price, though: EIS necessitates specialized impedance analyzer equipment, is sensitive to measuring temperature and SoC, and requires skilled individuals for spectrum interpretation. According to Heymans et al. (2014), EIS-based characterization raises the cost of battery repurposing per unit by 15–25%. This is a significant increase that needs to be supported by a corresponding increase in deployment dependability.

A third paradigm is represented by machine learning techniques. ML techniques may forecast remaining useful life using regular operational data, such as voltage, current, and temperature, without the need for additional equipment by training prediction models on sizable ageing datasets (such as NASA PCOE and Oxford Battery Degradation Dataset). Recent research has shown that RMSE for SoH prediction inside the training distribution is less than 1%. The

main drawback, though, is generalization: models trained on legacy data may show notable error on out-of-distribution packs as the diversity of EV battery chemistries—NMC, LFP, NCA, and upcoming solid-state chemistries—increases. Over the next 10 years, this risk will increase as the second-life supply chain includes chemicals for which there is currently little training data.

SoH Method	Accuracy	Cost	Field Deploy-ability	Diagnosis Depth	Best Use Case
Coulomb Counting	Moderate ($\pm 3\text{--}5\%$)	Very Low	Excellent	Low capacity only	Initial triage and real-time monitoring
EIS	High ($\pm 1\text{--}2\%$)	High	Limited	High resistance, kinetics, diffusion	Detailed screening of borderline/high-risk cases
Machine Learning	High ($\pm 1\%$) in-distribution	Moderate	Good if BMS data available	Moderate predictive, not mechanistic	Remaining useful life projection for qualified packs
Hybrid (Recommended)	Highest	Moderate-High	Good	Comprehensive	Full qualification workflow for second-life deployment

In conclusion, there isn't a single SoH estimating technique that works well in every second-life application scenario. The evidence is in favour of a risk-stratified hybrid method that uses ML to forecast the remaining useful life of qualifying packs, EIS for detailed diagnosis of borderline instances or high-risk applications, and coulomb counting for cost-effective initial screening. This synthesis—moving away from the query, "What is the best method?" to "which combination is best for particular risk level?"—represents a significant analytical addition that goes beyond the descriptive comparisons contained in most of the material currently in publication. Individual techniques show promise in controlled settings, but in real-world situations including the evaluation of second-life batteries, their shortcomings become apparent. This suggests that a single-method approach is inadequate, highlighting the necessity of an evaluation technique that is hybrid and application-specific.

Second-Life Application Feasibility

Second-life EV batteries' viability for stationary storage varies greatly depending on the application situation, necessitating a varied evaluation rather than a single, general conclusion. The most technically and commercially promising second-life sector, according to Casals et al. (2017), is stationary storage; however, their research did not fully take into consideration the diverse risk profiles associated with various application kinds.

Solar PV peak shaving and wind energy smoothing are examples of renewable energy storage that exhibit comparatively shallow, partial cycling at regular daily periods. The operating properties of older lithium-ion cells, which usually show more consistent performance during shallow cycling than under the deep discharge circumstances of main EV use, are especially well-matched to this profile.

Compared to energy-focused applications, grid stabilization services (frequency regulation, voltage support) place greater peak power demands on battery packs and are therefore more susceptible to resistance degradation since they require quick response times and brief cycling.

Although the economic case for home second-life storage is sometimes weak, residential storage has a unique risk profile. Installations in occupied buildings require greater safety assurance than utility-scale grid installations. Under favorable power pricing assumptions, Heymans et al. (2014) showed positive net present value for residential second-life storage; however, their model relied on accurate SoH classification and minimal repurposing costs, which are not always met in current practice.

The systematic inability to take into consideration the relationship between application load profile and second-life battery deterioration rate is a key gap in current feasibility evaluations. Even with the same SoH, a battery used in a grid stabilization application with high-rate partial cycling will deteriorate more quickly than one used in a low-rate renewable energy buffer. This indicates that application-specific cycle life projection is necessary to estimate the second-life lifespan and, consequently, economic value from initial SoH alone. This application-SoH interaction will be a key element of Stage 4 feasibility assessment in the evaluation framework created by this study. The prediction accuracy of current feasibility studies is limited because they frequently overlook the relationship between degradation characteristics and application load profiles. This highlights the need for integrated, context-aware evaluation models that account for both degradation characteristics and application-specific operational conditions.

Thermal Safety in Second-Life Systems

Cell-level temperature monitoring (as used in the xStorage architecture depicted in Figure 3), conservative charge/discharge window management, gas detection systems for early-stage thermal event identification, and fire suppression systems are examples of mitigation techniques reported in the literature. Nevertheless, rather than addressing the underlying causes of heat disturbances, these actions are reactive rather than proactive. This research recommends a more basic method as a requirement for high-risk applications: characterizing the thermal safety margin of particular battery populations using calorimetric testing of representative samples prior to deployment.

Research Methodology

Research Philosophy and Design Justification

This study takes a positivist research philosophy, based on the methodical gathering, examination, and interpretation of documentary and empirical data. A mixed-methods

research design is used, combining structured case study analysis, qualitative literature synthesis, and quantitative analysis of published battery ageing datasets. Rather of being a limitation, the decision to use a desk-based analytical process instead of main experimental testing is purposefully justified. Primary experimental testing of enough battery populations to reach statistical significance for a master's-level research paper would involve laboratory facilities, supplies, and timeframes that are beyond the purview of a single investigator. More significantly, at this point, a thorough synthesis of the available evidence—which is extensive but dispersed represents a higher-value contribution than incremental experimental data from a small sample. The suggested approach will provide a path for further empirical research by clearly identifying the experimental validation studies that are required as future work.

Systematic Literature Review

Following databases such as Scopus, Web of Science, IEEE Xplore, and Google Scholar, a systematic literature review will be carried out following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology to guarantee repeatability and transparency. The following Boolean search words will be combined: ('second-life battery' OR 'repurposed EV battery') AND ('stationary storage' OR 'energy storage') AND ('State of Health' OR 'SoH' OR 'degradation' OR 'thermal safety'). Peer-reviewed journal papers, conference proceedings, and technical reports; publication years 2011–2025 (with seminal earlier works included on the basis of academic merit); and direct relation to one or more research objectives are the inclusion criteria.

Battery Degradation and SoH Comparative Analysis

To explain degradation trajectories across various operational settings and chemistries, open-access battery ageing datasets such as the NASA Prognostics Data Repository, Oxford Battery Degradation Dataset, and CALCE Battery Research Group datasets will be studied. Degradation variability will be measured, and important determinants of second-life performance will be found using statistical techniques like principal component analysis and regression analysis.

Mean absolute error (MAE), root mean square error (RMSE), and maximum absolute error will be used to compare the three SoH estimate methods to these datasets. Crucially, the assessment will evaluate performance under the data availability constraints characteristic of actual second-life screening circumstances, such as partial cycling histories, varying SoC at arrival, and mixed chemistries, in addition to ideal conditions (full data availability, controlled protocols). Compared to assessments carried out under ideal circumstances, this stress-testing of method performance under realistic limits is meant to yield recommendations that are more realistically applicable.

Case Study Analysis

Structured case studies of the stationary storage deployments at Nissan xStorage/Johan Cruyff Arena, BMW/Vattenfall Hamburg, and Renault will be examined utilizing a standard system architecture and battery type; SoH assessment methodology used at repurposing; performance outcomes (cycling behavior, capacity retention); safety occurrences or near-misses; and economic performance. Recurring obstacles and common elements linked to successful deployment will be found through cross-case synthesis.

Framework Development and Validation

Iterative synthesis will be used to build the five-stage evaluation framework, which will be verified by: (a) consistency testing against all stated case studies—would use of the framework

have accurately classed each deployment as suitable or unsuitable? (b) expert evaluation in accordance with published recommendations from the IEC, EUCAR, and EU Battery Regulation (2023); and (c) sensitivity study that looks at how framework outputs alter under different assumptions regarding deterioration trajectory uncertainty and SoH estimation accuracy. The mixed-methods approach is selected to ensure both analytical depth and practical relevance. Quantitative dataset analysis enables objective evaluation of degradation trends and SoH estimation accuracy, while qualitative case study analysis provides insights into real-world deployment challenges. This integrated approach enhances the robustness and applicability of the proposed evaluation framework.

Expected Outcomes and Contributions

The primary contribution of this research is the development of a structured five-stage evaluation framework that integrates degradation analysis, state-of-health estimation, safety assessment, and application-specific feasibility into a unified decision-making methodology.

- A critical, quantitatively grounded description of EV lithium-ion battery degrading variability that argues for multi-parameter, pathway-aware assessment and shows that SoH alone is insufficient for second-life qualifications.
- A thorough comparative analysis of SoH estimating methods, resulting in a tiered, risk-stratified methodological proposal that goes beyond the literature's current descriptive comparisons.
- An evidence-based feasibility analysis that considers application-specific cycle life projection as a crucial factor in determining economic value in a variety of second-life application situations.
- A critical examination of thermal safety issues in second-life battery systems, pointing out shortcomings in existing regulations and suggesting a risk-stratified, proportionate safety characterization method.
- The main original contribution is a five-stage technical evaluation framework that offers a reproducible, practically applicable approach that is currently lacking in both established industry practice and academic literature.

By offering a technological foundation for second-life performance and safety criteria, the research will immediately help the implementation of the EU Battery Regulation (2023) while also making scholarly contributions to sustainable battery management, EV lifecycle analysis, and stationary energy storage. Its useful contributions meet the needs of regulatory agencies, energy storage integrators, automakers, and second-life repurposes.

Ethical Considerations

There are no human subjects, animal subjects, or private information involved in this desk-based study. There is less ethical risk because the research is guided by the following principles:

- Academic integrity: Every intellectual contribution shall be properly cited in accordance with Harvard style. Results and data will be accurately provided.
- Data transparency: Source, access date, and license restrictions will be used to identify each dataset. Limitations on the representativeness or quality of the data will be revealed.
- Generative AI compliance: AI tools have only been utilised for structural assistance and proofreading in line with the ACHA7027 specification. The student is responsible for all written analysis and research content.

As mandated by the ACHA7027 module requirements, an ethics form will be filled out and submitted through Turnitin. The report is deemed unsuccessful if the ethics form is not submitted.

Limitations and Mitigation

Limitation	Impact on Research	Mitigation Strategy
No primary experimental testing	Findings based on secondary dataset analysis	Multiple independent datasets; triangulation across sources; explicit future work agenda for empirical validation
Dataset heterogeneity across chemistries	Limits direct cross-chemistry comparison	Subgroup analysis by chemistry; sensitivity analysis on cross-chemistry assumptions
Rapid technology evolution	Findings may require updating as new chemistries enter second-life supply chain	Framework design prioritizes methodology over chemistry-specific parameters; structured for future updating
Case study context-dependency	Installation-specific lessons may not fully generalize	Multiple geographically and technically diverse cases selected; cross-case synthesis to identify generalizable principles
SoH framework unvalidated experimentally	Recommendations unconfirmed by primary experimental data	Consistency validation against published cases; explicit identification of experimental validation studies needed

Research Timeline

The suggested sixteen-week research timetable is shown below. The methodical movement from the basis of literature to technical investigation, framework development, and final reporting is ensured by the phased structure.

Ph.	Activity	Wk 1-3	Wk 4-6	Wk 7-9	Wk 10-12	Wk 13-14	Wk 15-16
1	Literature Review on EV Battery Degradation & Second-Life Applications	Weeks 1-3					
2	Analysis of Lithium-Ion Battery Degradation Mechanisms		Weeks 4-6				
3	Evaluation of SoH Estimation Methods			Weeks 7-9			
4	Case Study Analysis & Framework Development				Weeks 10-12		
5	Data Analysis and Second-Life Performance Evaluation					Weeks 13-14	
6	Final Report Writing, Review & Submission						Weeks 15-16

Phase 1 (Weeks 1-3) uses a thorough literature study to lay theoretical and empirical groundwork. Phases 2–3 (Weeks 4–9) deal with SoH comparative evaluation and degradation mechanism investigation. Phase 4 (Weeks 10–12) creates the framework structure and incorporates case study evidence. Phase 5 (Weeks 13–14) involves data synthesis and feasibility assessment. The structured report writing, critical evaluation, and final submission are all scheduled for Phase 6 (Weeks 15–16).

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