# State of health estimation of Li-Ion Batteries and their economic value for a second-life

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This thesis tackles challenges in the rapidly growing lithium-ion battery sector, exploring a circular economy approach to enhance sustainability and resource efficiency. It examines existing SoH estimation as well as economic value models for second-life batteries, and presents a novel approach to calculating SoH and predicting economic value, offering significant insights for creating a sustainable, circular lithium-ion battery ecosystem.

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## Introduction and Objective

Lithium-ion batteries are essential in sectors like mobility, energy, and consumer electronics. Their production presents challenges in lithium mining and recycling. Adopting a circular economy approach can address these issues, enhancing sustainability. This study aims to develop a circular lithium-ion battery ecosystem by examining existing State of Health (SoH) and economic value calculation models, creating and comparing SoH methods, and predicting the economic value of second-life lithium-ion batteries.

## Research Design

A literature review was conducted to understand current SoH estimation and economic value prediction methods. The BFH-developed data pipeline validated a novel SoH estimation method using histogram data. Machine learning algorithms were tested using NASA lithium-ion dataset, which was conducted in a labratory environment, with further validation from real-world data from an electric vehicle manufacturer.

## Results

The thesis provides insights into lithium-ion battery lifecycle management. A novel SoH estimation method was validated in combination with various machine learning algorithms' effectiveness. A feature importance analysis identified key factors in determining the reamaining useful life of a battery and thus its economic value at the end of the first life. A novel economic value landscape for these batteries was developed considering both internal and external elements such as the most important features resulting from the feature analysis, regulatory environments, and market needs. This integrated approach significantly contributes to a circular lithium-ion battery ecosystem and sustainable resource management.

## Implications and Recommendations

This thesis supports the transition into a circular economy in the lithium-ion battery industry with:

**Lack of Standardization:** One significant finding is the absence of a universally accepted classification framework for SoH estimation methods. To address this, a suggested classification framework is introduced. This proposed framework could serve as a basis for creating a standardized method of assessing the SoH, enhancing the comparability of results across different studies and applications.

**Differentiation between Timeseries- and Histogram-Based ML Approaches:** There is currently no differentiation between timeseries- and histogram-based machine learning approaches within the SoH estimation methods. It's recommended to introduce such a differentiation, which could enhance the discussion about which SoH estimation methods are most accurate for which purpose.

**Computation and Memory Requirements:** The study did not investigate in detail the computational and memory requirements of different SoH estimation methods. This would be an essential aspect to ensure the practicality of the methods in real-world applications, especially in devices with limited computational resources.

**Price Estimation Model for Second-Life EV-Batteries:** On the economic aspect, there's currently no available model for price estimation for second-life EV batteries. The development of such a model could greatly enhance the profitability and viability of battery repurposing and recycling efforts.

**Feature Importance Investigation:** The feature importance investigation of the SoH estimation model can serve as parameters for the economic model. This could provide a comprehensive understanding of the factors influencing the economic value of second-life batteries, thereby enabling more accurate and effective pricing strategies.