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# LCA CASE STUDY OF NCM BATTERIES WITH END-OF-LIFE RECOVERY VIA PYROMETALLURGICAL PROCESSING

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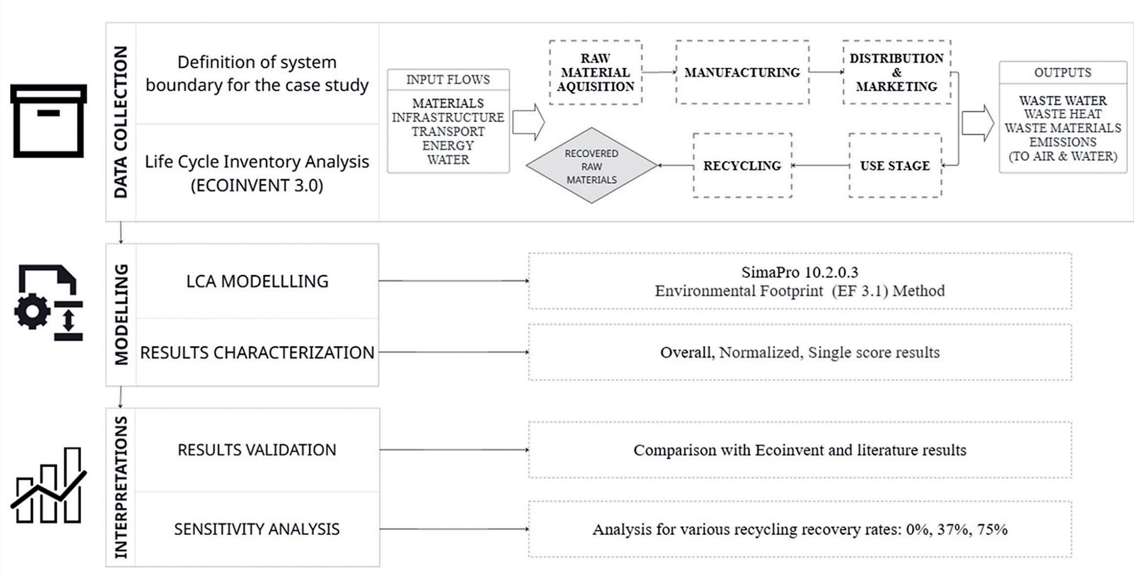
***Abstract*** – This study performs a cradle-to-grave Life Cycle Assessment (LCA) of Nickel-Cobalt-Manganese (NCM) lithium-ion (Li-ion) batteries to evaluate their environmental performance across all life stages. The analysis is conducted using SimaPro 10.2.0.3 software with the Ecoinvent 3.10 database, following the Environmental Footprint (EF) 3.1 method and ISO 14040/14044 standards. The research system boundary includes resources and processes of the battery life stages from raw material acquisition, manufacturing, distribution and marketing, operational use, to the end-of-life (EoL) recycling through the pyro-metallurgical process. Analysis results reveal that battery production is the most significant contributor to environmental damage, particularly in categories such as climate change and resource use, due to high-energy manufacturing and the extraction of critical raw materials. While the use phase adds moderate greenhouse gas emissions, the distribution phase has a negligible impact. A primary focus on EoL recovery shows that pyrometallurgical recycling provides substantial environmental benefits, specifically in reducing fossil fuel, metal, and mineral resource depletion, by reclaiming valuable materials such as cobalt, nickel, and copper. These credits help offset production-related impacts by reducing the need for primary material extraction and refining. However, the recycling process introduces minor trade-offs, such as increased acidification burdens. The results are validated by comparing with other literature and the Ecoinvent analysis results. The deviations in results indicate the effects of geography, processes, and technology choices on the inventory. Sensitivity analysis further demonstrates that maximizing recovery rates is essential, as lower efficiency leads to a significant increase in the overall environmental footprint. These results highlight the necessity of advanced recycling technologies and improved production efficiency to support sustainable electric mobility. The novelty of the study lies in its comprehensive, cradle-to-grave approach, particularly its quantification of recycling, which demonstrates how recycling can provide significant economic benefits that help offset production-related impacts. The study also provides a transparent life cycle inventory (LCI) to help decision-makers evaluate the environmental performance of design and technology choices. This study addresses that gap by conducting a detailed LCA to demonstrate the impact of inputs at each stage, and the outcome can be strategically managed to achieve a sustainable battery life cycle. By analysing environmental damage and impact trade-offs across life stages, the study supports informed decision-making for sustainable battery management in electric mobility, emphasizing the need for improved production efficiency and advanced recycling technologies to minimize overall environmental footprint. The results show that, while production remains in the dominant hotspot, end-of-life recycling significantly improves the sustainability profile of LIBs, making closed-loop material recovery essential for future battery systems. This analysis and observations can also serve as a base case for future research on the lithium battery LCA, especially for comparing different EoL scenarios.

***Keywords* – *Climate change; critical raw materials; electric mobility; Life Cycle Inventory; pyro-metallurgical recycling; sustainability***




LCA framework of the NCM lithium-ion battery for the case study

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