Design for disassembly: The influence of EV battery pack designs on environmental impact and circularity beyond the first life cycle

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EXTENDED ABSTRACT

In recent years, lithium-ion (Li-ion) batteries have become essential to the global automotive industry, transforming vehicle power solutions. As the market for these batteries continues to grow, battery disposal has become a significant concern (Ding et al., 2019). In light of the climate crisis and resource scarcity, the traditional linear economic model of "take-make-dispose" is becoming unsustainable (Mayyas et al., 2019). This practice is increasingly being replaced by the restorative framework of the Circular Economy (CE). To effectively implement CE principles, an eco-design strategy, such as designing for disassembly, can be integrated at the beginning of product development of Li-ion battery packs. This approach ensures that battery packs can be dismantled efficiently, facilitating sustainable practices—such as recycling, repair, and reuse—at the end of their life cycle (El Jalbout & Keivanpour, 2024). Battery packs used in certain applications are subject to a higher risk of damage, particularly in electric two-wheelers, where accidents are reported to be 6 to 13 times greater than that of other vehicle types (Yousif et al., 2020).

https://doi.org/10.25364/978-3-903374-48-5_03

To address this increased risk, the present study incorporates a crash scenario within the first product life cycle stage, thereby extending the scope of environmental impact assessment beyond conventional phases—design, use, and end-of-life—to include the potential for repair. The objective is to examine the environmental benefits and trade-offs associated with design for disassembly, particularly as they manifest across different life cycle stages and environmental indicators. A comparative analysis is conducted on three battery pack configurations with varying degrees of dismantlability: a non-dismantlable sealed housing and two dismantlable alternatives (exchangeable lids and liquid-filled battery). The product system of the LCA is given in Figure 1.

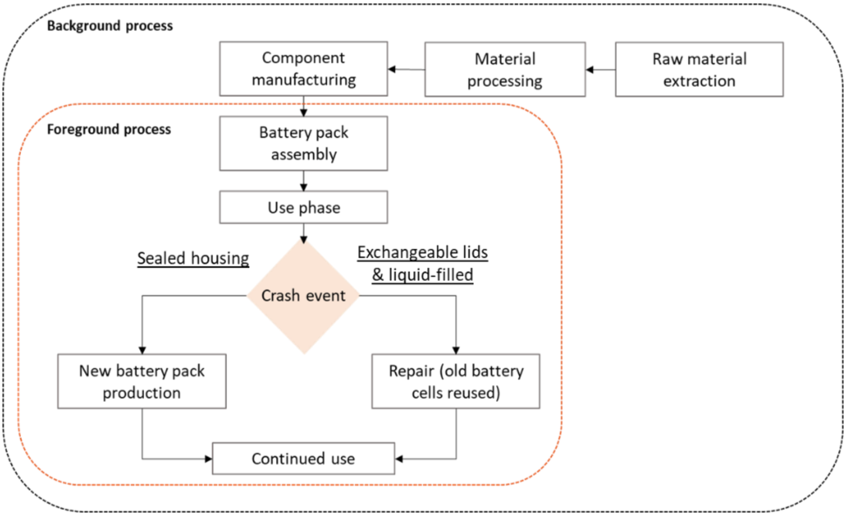

Figure 1. Production systems of the three battery packs, crash and replacement scenario included

Given that the focus of LCA is to evaluate environmental impacts, circularity assessments will be conducted to quantify the effects of different design-for-circularity measures. Our analysis is driven by the following key research questions:

1. How does the level of dismantlability in electric two-wheelers battery pack designs influence environmental impacts across multiple life cycles?
2. What are the trade-offs between circularity and environmental impact within the different designs?

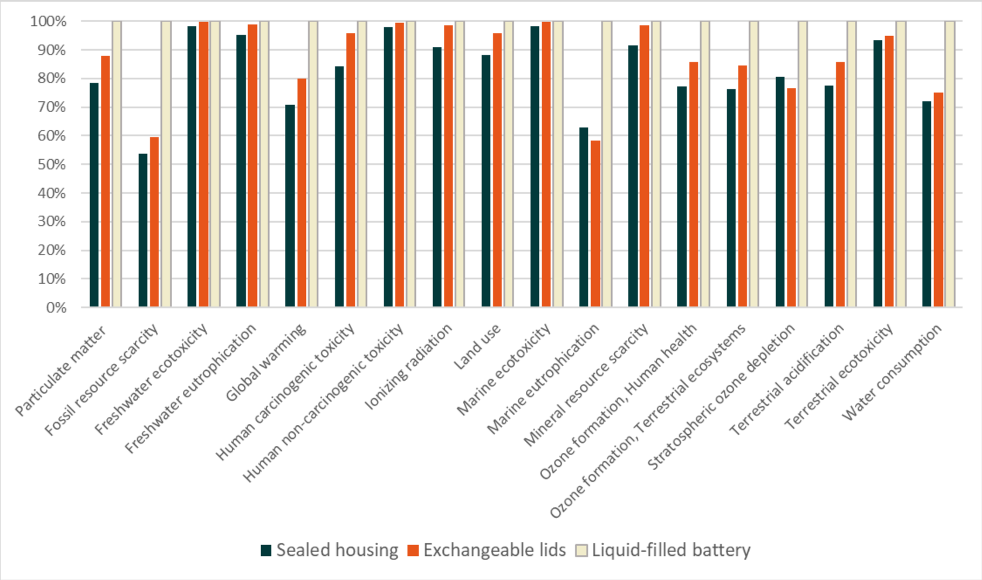

Figure 2. Relative environmental impact of the production phase for three battery pack designs, evaluated across multiple impact indicators - in relation to the highest contributor (set as 100%)

The outcome of this study provides an overview of the environmental impact and circularity of design for disassembly not only on the first product life cycle but also on the potential second life cycle considering repair. The results show that, during the initial life cycle, battery packs designed for disassembly are associated with higher environmental impacts, as illustrated in Figure 2. This suggests that enabling reparability in this context incurs additional material usage and environmental burden related to the battery housing and the choice of gap filler. However, the environmental impacts are reduced following a crash, when repairability becomes relevant primarily due to the reuse of battery cells. Although the environmental impacts increase, design for disassembly aims to ultimately improve the sustainability of the new battery packs by enhancing the circularity. Emphasizing the use stage, the added weight of dismantlable battery packs results in greater energy demands for motorcycle operation, illustrating how design decisions influence performance in later stages. To assess the benefits of enhanced circularity, suitable circularity metrics, such as circularity indicators which assess materials and/or products, need to be identified and applied. A variety of circularity indicators are proposed in the literature, ranging from indicators which consider environmental, economic and/or social aspects. Suitable indicators, which are able to capture the consequences of a design for disassembly will be applied to the case study in this work. This study highlights the environmental trade-offs and circularity benefits of design for disassembly in electric two-wheeler battery packs. While dismantlable designs show higher initial impacts, their potential for repair and reuse after damage supports long-term sustainability and resource efficiency in line with circular economy goals.

ACKNOWLEDGEMENTS

Parts of this research were conducted within 'E-Track - Design guidelines for the development of sustainable, safe and cost-optimised Traction batteries'. An AI tool has been used to improve the style and grammar of the language.

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