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Koroma, Michael Samsu; Mesquita Bordalo Da Costa, Daniele; Messagie, Maarten; Cardellini, Giuseppe; Hosen, Md Sazzad; Philippot, Maeva

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Environmental Impacts of Battery Electric Vehicles: Implications of the Cascaded Battery Life Cycle and Yearly Charging Electricity

Michael Samsu Koroma[1,2], Daniele Costa[1,2], Md Sazzad Hosen[1,2], Maeva Philippot[1,2], Thierry Coosemans[1,2], and Maarten Messagie[1,2]

[1]Electrotechnical Engineering and Energy Technology, MOBI Research Group, Vrije Universiteit Brussel, Pleinlaan 2, Brussels 1050, Belgium;
[2] Flanders Make, 3001 Heverlee, Belgium

E-mail contact: michael.samsu.koroma@vub.be

1. Introduction

The transport sector contributes significantly to global environmental impacts, particularly to climate change. There are several ongoing initiatives to decarbonise the sector and reduce its emissions, such as battery electric vehicles (BEV). Life Cycle Assessment (LCA) studies on BEV are likely to overstate the life cycle environmental impacts because expected changes in the electricity sector are often not considered in the well-to-tank (WTT) analysis. The repurposing of BEV batteries for second-use is also often missing. The novel aspect of this study is to assess the environmental impact of a current BEV, considering the future changes in the share of Renewable Energy Sources (RES) in the EU electricity sector and the repurposing of the used BEV Li-ion Battery (LiB).

2. Materials and methods

An attributional LCA was performed. The functional unit was defined as driving a European B-segment BEV equipped with a 52 kWh LiB for a lifetime mileage of 160,000 km over 12 years. The LiB cells were repurposed for a residential application. The system boundary (***Figure 1)*** covers all the BEV life cycle stages, including its repurposed LiB cells, except for the use stage of the repurposed LiB. System expansion was considered to avoid allocation between repurposing the used BEV LiB. This approach allows the inclusion of an equivalent LiB (hereafter "avoided LiB") that the repurposed LiB might replace in real life.

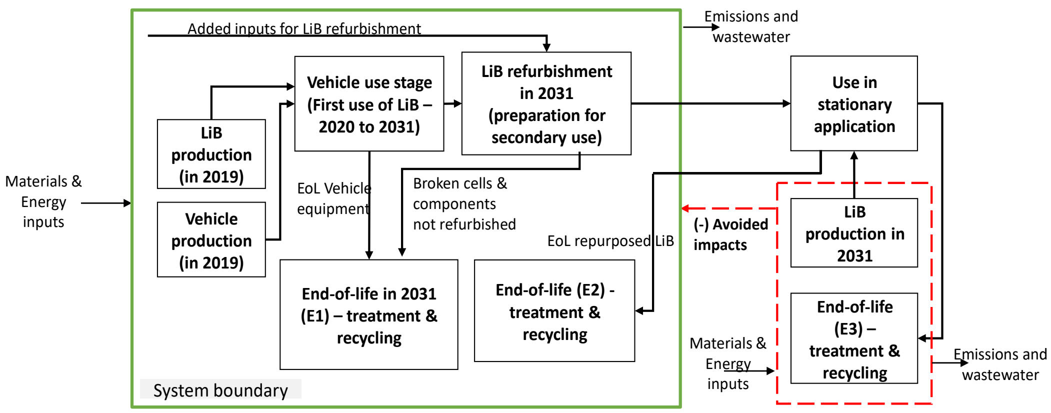

Figure 1. System boundary in solid green line and extended system boundary in red dotted lines.

The vehicle equipment production, the battery pack assembly, the use phase, and the End of Life (EoL) stages were assumed to occur in Europe. The production of the LiB cells was considered to occur in South Korea. Inventory data for vehicle manufacturing, including EoL, was based on Ecoinvent v3.6 [1]. Data for LiB manufacturing and EoL were based on the scientific literature [2,3]. The BEV use phase was modelled using the average EU electricity mix for each year (2020 – 2031), based on the "Stated Policies Scenarios" for the EU [4]. The BEV consumption was modelled, considering 16.9, 18.5, and 20.0 kWh/100km.

LiB refurbishment was modelled based on Richa et al. [5] considering the impacts of transportation and state of health test. Inventory data for the avoided LiB and the replacement of broken components in the repurposed LiB was also based on Ellingsen et al. [2]. The repurposed LiB was modelled, assuming 50% of the used LiB cells are viable for second-use for 10 years. The results' sensitivity was tested, considering 10% to 100% cell conversion rate (CCR) and a second lifetime of 1 and 5 years. The ReCiPe 2016 impact assessment method was used to conduct the assessment.

3. Results and discussion

The comparison of the different stages shows that GWP is mainly driven by the charging electricity (31.4%) and the LiB production (30.7%) (***Figure 2***). These values were calculated without recycling and LiB repurposing. When recycling was considered, an 11% reduction in GWP was noted. Additionally, the results show an 8% reduction in total GWP when changes in electricity mix are considered. Likewise, the total GWP was 3% lower with the repurposed LiB for second-use.

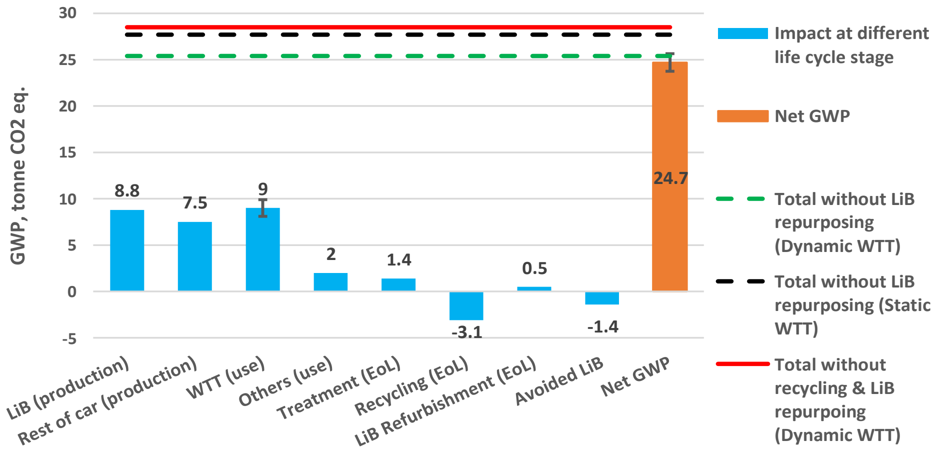

Figure 2. GWP impacts of a BEV with a cascaded battery life cycle. Static WTT means no changes in the electricity sector were considered, while Dynamic WTT implies changes were considered. Others (use) implies emissions of road, maintenance, and non-exhaust emissions. The error bars represent the parametric variability of BEV consumption.

The sensitivity analysis of these parameters showed that the benefits of the repurposed battery life cycle could be minimised when the CCR and the second lifetime are reduced. GWP reductions occur for a lifetime of 10 years and all CCR (0.5% to 6.1% lower). For a 5 years lifetime, GWP reductions started to be observed from a 40% CCR (0.1% to 0.5% lower). However, GWP increases for a lifetime of 1 year for all values of CCR (0.6 to 3.9% higher). These resuts are discussed relative to the baseline (10 years and 50% CCR).

4. Conclusions

In this paper, the impact of the cascaded battery life cycle and changes in the electricity sector on current BEV environmental performances has been quantified. The results showed that LCA studies on BEV are likely to overestimate the life cycle environmental impacts of current BEV by 8% since the expected changes in the share of RES in the charging electricity are overlooked. As a result, the environmental advantages of electric vehicles are likely minimised. The study found added benefits of LiB repurposing for a longer second lifetime and higher CCR. Additionally, it confirmed the importance of recycling to the environmental performance of a BEV.

5. References

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