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Life Cycle Assessment: Tools and Techniques for the Automotive Sector

By

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Abstract

Given the raising climate crisis and the automotive shift toward electrification, adopting sustainable practices is crucial. Life Cycle Assessment (LCA) provides thorough environmental analysis of products from raw material extraction to disposal, supporting manufacturers and stakeholders in making informed decisions towards sustainable advancement in road transport. To date, despite the availability of numerous LCA studies on vehicles in the literature, interpreting and comparing LCA results remains challenging due to significant differences in underlying assumptions. This lack of comparability stems from the absence of standardized methodological guidelines. This thesis explores the core principles of LCA, starting with a brief analysis of its definition, historical development and importance in regulatory discussions within the automotive industry. Then, various LCA approaches that are contributing to the advancement of LCA methodology in the automotive sector are explored. Case studies are used to illustrate the application of LCA to different automotive components and vehicles, identifying the challenges and limitations faced during its implementation. At component level, batteries, electric drivetrains, and hydrogen engines have been investigated. The decision to investigate batteries derives from the growth of the rechargeable battery market, driven by electrification and regulatory pressures. This growth elevates concerns about energy use, carbon footprint and resource scarcity. To address these environmental challenges, evolving LCA methodologies—including the new EU carbon footprint calculation rules and the adoption of prospective LCA (P-LCA)—are essential tools for evaluating and managing the sustainability of both current and future battery technologies. This thesis includes three case studies on this topic: (1) assessment of the impacts of a lithium-ion battery designed for light-duty commercial vehicles (LDCVs); (2) testing of the new Circular Footprint Formula (CFF) as proposed in the new EU regulation on waste batteries; (3) development of a P-LCA methodology for emerging EV batteries and application to four different and novel battery cells. The decision to

investigate electric drivetrains derives from the increasing EU regulatory pressure in improving drivetrain efficiency and reducing the use of rare earth elements in electric motors. This thesis includes three case studies on this topic: (1) assessment of the effects of an eco-design strategy applied to an electric motor; (2) evaluation of a novel recycling process for recovering permanent magnets; (3) assessment of EU current radial flux motors and in-wheel motors. Lastly, the decision to investigate hydrogen and carry out a focus on hydrogen engines derives from the actual need for certain vehicles in covering long-haul operations and working in special environments. Two case studies have been assessed: (1) the LCA models of diverse hydrogen production paths have been developed to assess current and potential well-to-tank environmental impacts; (2) then, these insights have been exploited to conduct cradle-to-grave LCA of a hydrogen engine. At vehicle level, four case studies have been examined: (1) diverse Life Cycle Inventory (LCI) modeling strategies have been tested on a driver seat to assess the trade-off between effort and result accuracy in LCI modeling. Then, (2) the methodology has been extended to light- and heavy-duty commercial vehicles. A diesel LDCV serves as a case study. After that, (3) the role of the EoL phase has been investigated on three LDCVs. Lastly, (4) two zero-emission trucks have been compared with their diesel counterparts. At last, the thesis points out future trends, which will open up doors for innovative LCA approaches that will further enhance sustainable development in the automotive industry.