Abstract

In the context of the global shift towards sustainable development and climate neutrality, the industrial and heavy-duty vehicle sector plays a pivotal role in achieving Circular Economy (CE) objectives and the Sustainable Development Goals (SDGs). This thesis explores circular transition strategies and sustainability performance assessment methods applicable to this sector, combining academic research with industrial case studies to provide a comprehensive framework for evaluating and supporting circular transitions.

A key outcome of this research is the development of CIRCuS-IV, a semi-quantitative tool to assess the circularity and sustainability of industrial vehicle manufacturers. Based on publicly available data, it evaluates environmental, economic, and social performance using three developed indicators: the T-index (transparency), the CEPE index (circularity and sustainability), and the SDG Transition Index. The tool was applied to leading companies of the sector (CNH, Daimler, Volvo Group), highlighting differences in transparency and CE commitment. The results provided circularity and sustainability performances of the case study companies and underlined the importance of robust, publicly accessible data in supporting transparent transitions toward sustainability.

The research also addresses the environmental implications of Lithium-Ion Batteries (LIBs) use in public transport fleets, quantifying the global warming potential (GWP) associated with different life cycle phases and geographic contexts. A detailed case study in Turin, Italy, showed that increasing the share of electric buses (64% of the fleet) can reduce CO_2eq emissions by up to 41%, highlighting the relevance of electrified transport solutions strategies for urban decarbonization. This analysis also showed gaps in life cycle data across global regions and lifecycle phases.

A core contribution of this work, conducted in collaboration with CNH, focuses on the extensive examination of remanufacturing as a circular strategy, particularly applied to electronic components and aftertreatment systems in industrial and HDOR vehicles. Case studies demonstrated the technical feasibility, significant environmental benefits (such as up to 98% reductions in CO_2eq emissions compared to new manufacturing) and notable economic savings associated with remanufacturing. Specifically, remanufacturing retained between 70% and 99% of the original material mass of electronic components, while customers experienced cost savings of 20–25% compared to purchasing new parts. Furthermore, remanufacturing contributed to reducing machinery downtime and resolved compatibility issues with obsolete spare parts, thereby enhancing operational efficiency. Similarly,

the remanufacturing of aftertreatment systems, that include diesel oxidation catalysts, diesel particulate filters, selective catalytic reduction devices, and ammonia slip catalyst, was shown to reduce the global warming potential by up to 42%, primarily through remanufacturing of DPF and steel casing. Therefore, this process retained approximately 90% of the ATS mass and reduced carbon emissions significantly compared to producing new units.

This work also identifies key barriers and enablers of remanufacturing adoption through the application of the DEMATEL method. Design for remanufacturing, economic benefit, process standardization, and technological readiness emerged as the most influential drivers, while regulatory frameworks and environmental awareness were identified as critical but less interactive external factors. This approach showed remanufacturing's potential to enhance circularity and sustainability within the industrial and HDOR vehicle sector.

In addition, sustainability indicators specific to remanufacturing was developed and validated using data provided by CNH and its suppliers. The indicators address four key dimensions: environmental, economic, efficiency and performance, and social, establishing a basis for standardized sustainability assessment practices within the industry. This multidimensional assessment enabled a comprehensive evaluation of remanufacturing impacts, from emissions reduction and energy performance to market dynamics and employment inclusiveness. Overall, this integrated approach underscores the role of remanufacturing as a key enabler of circularity and sustainability in the industrial and HDOR vehicle sectors.

In conclusion, this research provides a multi-layered framework to support the transition of industrial and heavy-duty vehicle manufacturers towards circularity and sustainability. By integrating assessment tools, real case studies and industrial insights, the thesis offers practical pathways for industries to accelerate CE adoption, reduce environmental impacts, and align with long-term sustainability goals.

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