Institute of Transport Economics
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ENGLISH Summary

Circularity and environmental impacts of passenger vehicles

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A significant transformation is underway in Norway's passenger vehicle fleet, driven by ambitious political targets as part of the country's green transition. While this transition will reduce tailpipe emissions and decrease vehicle fossil fuel consumption, it will also shift emissions upstream and increase reliance on various metals and minerals. Some of these materials are defined as critical in the EU with high supply risk. Moreover, the potential environmental benefits of electric vehicles (EVs) are dependent on several factors, including the carbon intensity of the electricity mix used for charging and the vehicles' usage patterns. Collectively, these aspects lead to a need for developing a more circular vehicle system and an increase in overall environmental sustainability.

This report provides an extensive review of circular economy (CE) principles and life cycle assessment (LCA) applications throughout different stages of a passenger vehicle's life cycle, mapping their sustainability perspectives and the interplay between these. The report comprises part of the CELECT project (Circular Economy, Life Cycle Assessment, Electrification and Car Transactions), which has the aim to provide research-based support towards the electrification of the Norwegian passenger vehicle fleet.

CE strategies aim to retain the value of materials within the system by extending product lifespans, reducing waste, and minimizing the need for new raw materials. For passenger vehicles, this involves strategies such as enhancing reuse, repair, refurbishment, and recycling efforts. LCA evaluates emissions, resource consumption, and environmental impacts throughout a vehicle's life cycle, from raw material extraction to end-of-life. The systems perspective that LCA offers is especially relevant for evaluating a transition from conventional internal combustion vehicles to electric vehicles due to the differing environmental profiles. However, applying these principles in isolation may not guarantee a combined reduction in environmental impacts alongside more circular product systems.

Circular Economy and Life Cycle Assessment: A Unified Approach

The review findings underscore the need to combine circularity and LCA approaches to achieve overall environmental sustainability while minimizing burden shifting. Together, the joint use of LCA and CE principles provides a holistic perspective, giving the potential to apply strategies

to increase vehicle circularity whilst ensuring a reduction of environmental impacts across all life cycle stages. This integration is essential as the automotive industry faces mounting regulatory pressures, particularly regarding EV batteries and their overall environmental footprint.

Supporting Policy

This report also reviews supporting policy since it provides a framework that industry must act within. The findings indicate that sustainability requirements will be greatly tightened in coming years, particularly for EV batteries.

Regulatory frameworks are critical in driving the automotive sector toward sustainable practices. The EU's new *Circular Economy Action Plan* identifies automotive and battery sectors as key targets for circularity principles. With the EU's new *Batteries Regulation*, more stringent sustainability requirements are being implemented, focusing on carbon footprint declarations, increased recycling efficiencies, and extended producer responsibility. In Norway, ambitious goals of achieving a zero-emission vehicle fleet by 2025 reflect the necessity for a greener transport sector. In addition, the country has developed its own *National Strategy for a Green Circular Economy* and *Norway's battery strategy*, focusing on recycling and managing EV batteries, as well as aligning with European Union regulations.

Key Findings and Research Gaps

Reviewing the research field allowed us to identify key circularity factors and LCA parameters, as well as evaluating research gaps that should be addressed in further LCA work. Nine research gaps were identified, including seven that are critical. These seven research gaps include:

Vehicle and battery lifetime: These parameters are handled in a generic manner, where typically vehicle lifetime is set to a certain number of years or mileage, while battery lifetime is often considered as equal to vehicle lifetime. Furthermore, differences in vehicle lifetime between powertrain technologies or model year are generally not considered. Some LCA studies address the battery lifetime uncertainty through an uncertainty analysis considering battery replacement, but this is not always the case.

Maintenance resource and energy needs: Maintenance resource and energy needs are often omitted or modelled in a generic manner using data from databases. If included, current LCA studies do not sufficiently distinguish the needs for different powertrain technologies or vehicle sizes/segments.

Operation energy use: Operational energy use is often modelled with an assumed energy use, sometimes using test data for one or several specific vehicle models on the market. Most studies tend to focus on medium sized passenger vehicles, while very few consider energy use of different vehicle sizes/segments.

Vehicle utility: LCA studies considering passenger vehicles do not tend to focus on user numbers (e.g. shared mobility) or capacity but rather on technologies. LCA studies tend to report impacts in terms of vehicle-kilometer (or per vehicle) while passenger-kilometer is primarily considered in studies comparing different transport modes (e.g., buses, planes, ferries). Effects of use characteristic variation (e.g. distance driven) are sometimes studied in LCA sensitivity analyses but are typically not based on real data regarding usage patterns.

Recyclability: Most LCA studies considering end-of-life treatment use generic data from databases or literature with no differentiation between powertrain technologies, size/

segments, or model year. Furthermore, statistics about recycling and recovery rates or reuse of components/materials are not considered specifically.

Vehicles and batteries end-of-life options: A growing body of literature is considering battery reuse, repurposing, and recycling. The access to real-life battery data is limited though and studies often base inventory data and analysis on coarse assumptions about battery life, as well as repurposing needs and second life application and durability.

Allocation between multipurpose utilities: Various allocation alternatives may be used in an attributional LCA to ascribe benefits of multipurpose use of components. Physical (i.e., energy) and economic allocation are particularly relevant, but LCA studies tend to set the allocation keys based on assumptions of use and lifetime, rather than real-life data.

For the seven key research gaps identified, we aim in the CELECT project to collect real-world data from project partners (i.e. key stakeholders in the vehicle industry) to develop more complete, accurate and comprehensive life cycle inventory models.

The Road Ahead

Achieving a fully circular and sustainable automotive sector will require research together with innovation from the industry and continued support from regulatory bodies. By assessing CE strategies together with LCA, and filling the identified research gaps, meaningful steps toward sustainability can be mapped out.

This work will offer valuable scientific insights that can form the foundation for future research, contributing to a more sustainable automotive sector. While it may not directly influence policy in the short term, it aims to provide essential knowledge that can inform future developments in research, policy and industry practices.