Institute of Transport Economics
Norwegian Centre for Transport Research

ENGLISH

Summary

The end of the ICE age?

Life cycle assessment of diesel, fuel cell, and battery electric heavy-duty freight vehicles

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This study uses life cycle assessment (LCA) to compare the environmental performance of diesel, fuel cell, and battery electric powertrains for 50-ton freight vehicles across five impact categories. The results indicate that electric vehicles have lower impacts in two categories, including climate change, while the diesel vehicles perform better than both electric powertrains in three of the five categories. While climate change is the primary driver for electrification, decision-makers in industry and policy must consider the environmental trade-offs and potential problem shifting associated with each powertrain alternative to minimize other environmental impacts. Therefore, policymakers should promote effective recycling and circular economy practices, such as battery recycling, repurposing, and reuse, which can help mitigate production-related environmental impacts and reduce supply chain dependency. The transition to electric vehicles must be guided by a robust and comprehensive understanding of their full life cycle impacts to ensure sustainable outcomes. Given the rapid pace of technological advancements, this requires regularly updated LCAs.

Background

In Norway, greenhouse gas (GHG) emissions from the heavy-duty vehicle sector have increased significantly since 1990, and meeting emission reduction targets by 2035 presents major challenges. Transport activity is expected to grow faster than the benefits of technological advancements of diesel engines and trucks and increased biofuel blending, prompting exploration of fuel cell and battery electric powertrains as alternatives to diesel powertrains for heavy-duty freight vehicles. To assess the environmental impacts of these powertrain technologies, this study applies the LCA method to evaluate their environmental impact throughout their life cycle.

While most LCA studies focus on GHG emissions, they often overlook other environmental impacts. Some LCAs only partially consider the life cycle, excluding commonly used vehicle components or necessary infrastructure. Furthermore, technology descriptions are often incomplete, and some studies suffer from outdated or inappropriate inventory data for heavy-duty applications. Additionally, none of the studies consider vehicles with a 50-ton gross weight, which are more prevalent than 40-ton trucks in Norway. This study addresses these gaps by focusing on the life cycle environmental performance of 50-ton freight vehicles in Norway.

Method

The study compares diesel, hydrogen fuel cell, and battery electric powertrains for both regional trucks with trailers and long-haul tractors with semi-trailers. The goal is to provide insights into the environmental performance of these technologies, supporting decision-making for fleet operators and policymakers. The LCA considers the entire life cycle—from cradle to grave—including both the equipment and energy carriers. The equipment life cycle includes the vehicle and cargo transport units (trailers and semi-trailers), covering material extraction, component manufacturing, assembly, operation, maintenance, and end-of-life treatment. The life cycle of the energy carriers, commonly referred to as Well-to-Wheel (WTW), covers both Well-to-Tank (WTT) and Tank-to-Wheel (TTW). For all energy carriers, the life cycles of the necessary infrastructure, including refuelling stations and battery charging stations, were included in the WTT phase.

The functional unit of the study is defined as "the delivery of one ton of freight over one kilometer," with environmental impacts reported per ton-kilometer (tkm). This accounts for differences in load capacity in terms of weight between vehicle configurations and powertrain technologies. For further reference, results expressed on a per-vehicle basis (without accounting for variations in cargo capacity) are provided in Appendix B.

The assessment focuses on five environmental impact categories: climate change, freshwater ecotoxicity, terrestrial ecotoxicity, terrestrial acidification, and photochemical ozone formation related to human exposure. These categories were selected for their relevance to vehicle technologies. Impacts were calculated using the ReCiPe 2016 characterization method in the openLCA software.

Results

The results revealed trade-offs in environmental performance across powertrain technologies. Electric vehicles had lower impacts in climate change and ozone formation, primarily due to reduced impacts during the use phase. Diesel vehicles performed better than both electric powertrains in three of the five impact categories: freshwater toxicity, terrestrial toxicity, and terrestrial acidification. Among electric vehicles, battery electric vehicles exhibited lower impacts in freshwater ecotoxicity, terrestrial acidification, and ozone formation, while hydrogen fuel cell vehicles had lower impacts in terrestrial ecotoxicity. In terms of climate change, both vehicle types had similar impacts, with battery electric vehicles having an advantage in regional applications, while fuel cell vehicles slightly outperformed battery electric vehicles in long-haul scenarios.

When comparing powertrain technologies, it became evident that electrification generally incurs higher production impacts compared to diesel vehicles. Our findings suggest that electric vehicles will struggle to offset their higher production impacts in categories such as freshwater ecotoxicity, terrestrial ecotoxicity, and terrestrial acidification. The use of metals in powertrain production and energy carrier life cycles was a significant contributor to these impacts, as electric vehicles typically rely more heavily on metals than their diesel counterparts. While both electric powertrains may achieve a net life cycle benefit for climate change, stricter constraints apply to fuel cell vehicles compared to battery electric vehicles, which are more likely to succeed due to their more efficient energy life cycle.

Discussion and conclusion

The findings underscore the importance of considering all life cycle stages and several environmental impact categories to gain a comprehensive understanding of the environmental performance of different powertrain alternatives. A narrower focus—such as on just WTW or GHG emissions alone—would have overlooked the significance of components in electric powertrains and failed to highlight key differences between fuel cell and battery electric vehicles. The life cycle perspective is crucial for making informed, environmentally sound decisions that guide both fleet managers and policymakers. That said, climate change mitigation remains the primary driver for electrification. When using the Norwegian electricity mix for hydrogen production via electrolysis and battery charging, both fuel cell and battery electric trucks offer net life cycle climate benefits.

Future studies should address data uncertainties, particularly for electric powertrains, and account for rapid technological advancements, especially in fuel cells and Li-ion batteries. Policymakers should prioritize R&D funding to ensure that LCAs reflect the latest developments in battery technologies, hydrogen production, and recycling processes. This will be crucial for supporting the transition to a more environmentally sustainable transportation system.