Comparative Life Cycle Analysis of Automobiles: ICEV vs. EV

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1. Introduction and Goal Definition

Transportation is a major contributor to global emissions, accounting for 15% of the total in 2019 (IPCC, 2022, Jaramillo et al., 2023). By 2022, it became the largest contributor to U.S. direct greenhouse gas (GHG) emissions, making up 28% (EPA, 2024). Internal Combustion Engine Vehicles (ICEVs) are responsible for over 94% of these emissions, primarily from petroleum-based fuel, with passenger cars alone accounting for 20% (EPA, 2024). Achieving Net Zero Emissions (NZE) requires an annual CO_2 reduction of over 3% from the transport sector by 2030 (IEA, a&b, 2023). Electric Vehicles (EVs) offer a promising solution, potentially reducing energy use and GHG emissions, especially when powered by renewable energy sources (IEA, a&b, 2023). This comparative Life Cycle Assessment (LCA) study aims to assess the environmental impacts of ICEVs and EVs, facilitating informed decisions for a sustainable future. The study focuses on the energy and GHG emissions, enables us to decide which option has less environmental impact, and provides recommendations on further decreasing these impacts.

2. Methods, Data, and Inventory

2.1. System Boundary and Functional Unit

This study employs a cradle-to-grave LCA, encompassing raw material extraction, use phase, and end-of-life treatment. The functional unit is defined as 1 vehicle-km. Key environmental parameters include vehicle lifespan, energy usage and sources, and raw material use. ICEVs are assumed to have a lifespan of 150,000 km with an energy usage of 6.19E-2 kg/FU, while EVs have a lifespan of 225,000 km with 0.26 kWh/FU. Four energy sources for electricity production are considered: European grid mix, photovoltaic, wind, and hard coal. Transportation modes include ship, train, and truck. Data from the Ecoinvent dataset and Gui's (2019) LCA on Tesla Model 3 were used. Initial calculations were performed in Microsoft Excel, followed by comprehensive LCA using OpenLCA software, with results verified through manual calculations (see Figure 1). The Impact World+ method was used for midpoint and endpoint impact assessments.

2.2. Life Cycle Inventory

The reference flows were considered through the following categories: manufacturing (materials and processing), transportation, use, and disposal. For the ICEV, there are 23 manufacturing process units (PCs), 3 transportation PCs, 2 use-phase PCs, and 5 disposal PCs. For the EV, there are 14 manufacturing PCs, 3 transportation PCs, 1 use-phase PC, and 6 disposal PCs.

Initially, the Energy and CO2 balances of ICEV and EV were calculated in Microsoft Excel using data from the Ecoinvent dataset and Gui's 2019 paper. Next, OpenLCA software is used to conduct a comprehensive life cycle analysis for both cases. The results were checked with the initial manual calculation. Midpoint and endpoint impacts were obtained from OpenLCA using the Impact World+ method.

3. Results and Discussion

3.1. Impact Assessment of ICEV

As shown in Figure 1, the EV with hard coal is the most impactful emission option. Besides that, the ICEV has a higher CO_{2eq} emission than the rest of the EV alternatives. The use phase is the most impactful LCA phase for ICEV (88%), EV with hard coal (90.96%), and grid-mix EV (80%). The manufacturing phase is the second impactful phase for ICEV (11.11%), EV with hard coal (8.66%), and grid-mix EV (18.94%). Similar trends also apply to the energy use.

While the EU-mix EV (Figure 1) generates half the emissions of ICEV, switching the energy source for recharging the EV to renewables substantially reduces the impact. Relatively, the total emissions of solar EVs are 17% of those for ICEV, and EVs with wind produce only 11% of ICEV. In these scenarios, the manufacturing phase is dominant, accounting for 84.65% of the EV with wind and 56.69% of the solar EV.

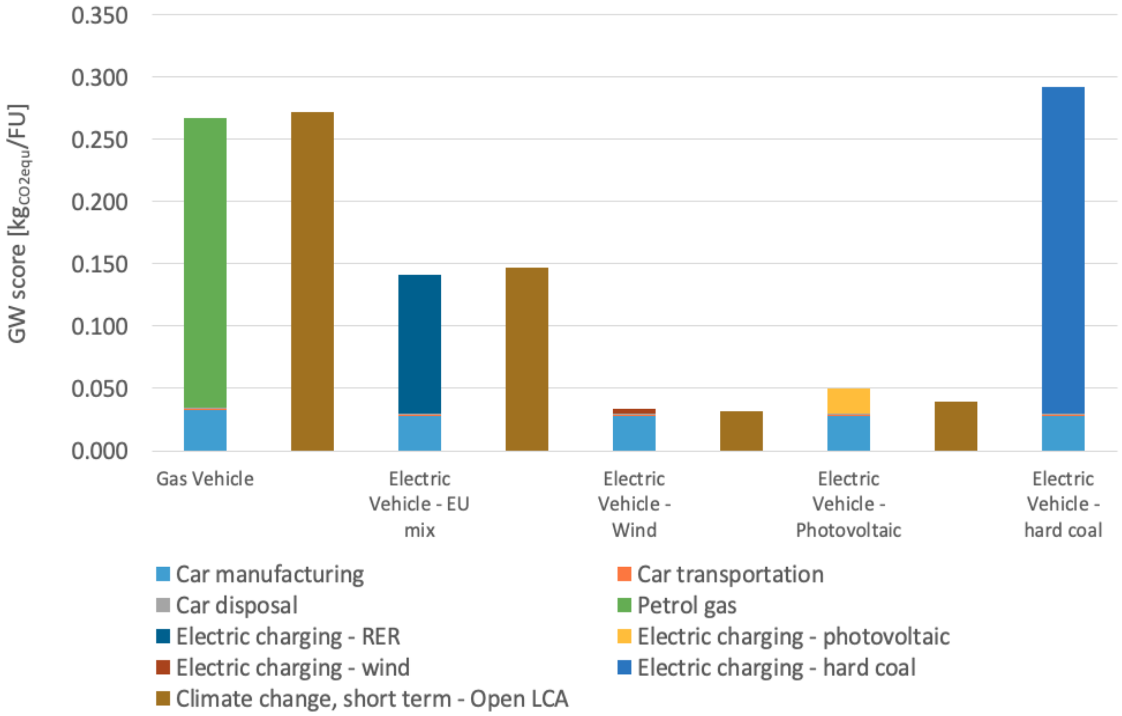

Figure 1. Comparison of Global Warming Score (kg CO2eq/FU). The brown bars show the OpenLCA results, which verify the manual calculations.

3.2. Alternative Scenarios and Comparison

Alternative scenarios considered varying lifespans and energy sources for electricity production (Figure 2). As illustrated in the inlet, ICEV is better at lifespans up to around 6000 km than all EVs. The break-even point is 6200 km for EV-wind, 6600 km for EV-PV, and 11800 km for EV-grid mix. It performs better than EV-hard coal for the entire lifespan range considered.

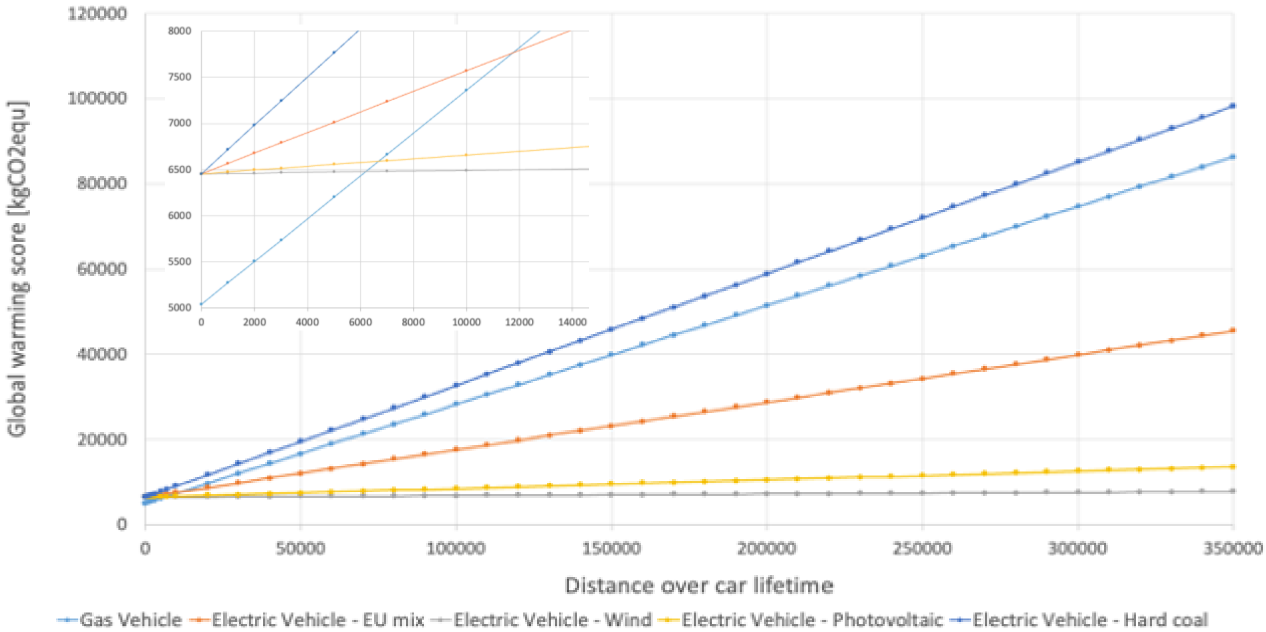

Figure 2. Cumulative Global Warming Score Over vehicle lifetime (kg CO2eq/FU)

Regarding the use phase and energy source, figure 2 shows the EV-wind has the best performance among all scenarios for CO_2 emissions. Relative to the total emission of ICEV, the total emission for EV-wind adds to 11.16% of the ICEV. While 84.65% of EV-wind emission is due to manufacturing, usage (petrol gas) is responsible for 88% of ICEV's emissions. EV with photovoltaic recharging is also a promising alternative that only emits 16.66% of the ICEV, where manufacturing and use contributions are comparable, 56.69% vs. 40.83%.

4. Conclusions and Recommendations

EVs using renewable energy sources are the most effective in reducing CO_2 emissions and energy use, with wind-powered EVs performing best. For ICEVs, the use phase is the dominant contributor to emissions, whereas the manufacturing phase is most impactful for EVs with renewables. This analysis recommends transitioning to EVs powered by renewable energy and focusing on reducing manufacturing emissions. Further research should improve manufacturing data accuracy to better understand the trade-offs between ICEVs and EVs and different electricity production methods.

5. References

[1]. EPA (2024). Sources of Greenhouse Gas Emissions. at: https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview. Accessed 07/03/2024.

[2]. Gui, G. (2019). Carbon Footprint Study of Tesla Model 3. In *E3S Web of Conferences* (Vol. 136, p. 01009). EDP Sciences.

[3]. IEA. a. (2023), Global EV Outlook 2023, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2023, Licence: CC BY 4.0.

[4]. IEA. b. (2023), Greenhouse Gas Emissions from Energy Data Explorer, IEA, Paris https://www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer

[5]. IPCC (2022), Emissions Trends and Drivers. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.004

[6]. Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead. (2022). Transport. In IPCC. (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.012