BME GPK

FACULTY OF MECHANICAL ENGINEERING

# Comparison of Environmental Impact of Electric Vehicles and Internal Combustion Engine Vehicles

Environmental impacts of Energy

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# 1. Executive Summary

This study evaluates and compares the life cycle environmental impacts of a battery electric vehicle (BEV) with multiple battery capacities and a conventional internal combustion engine (ICE) vehicle using ISO 14040/14044 methodology and ecoinvent data modeled in openLCA 2.5. The assessment covers cradle-to-use-phase stages including material extraction, car manufacturing, battery production, and use-phase energy consumption under several electricity mix scenarios. Results show that BEVs have substantially lower climate impacts when charged with low-carbon electricity, while BEV battery production increases mineral resource use relative to ICE vehicles. Scenario analysis highlights electricity mix as a dominant driver of environmental impact. Overall, BEVs outperform ICE vehicles in most impact categories when powered by renewable-rich grids, supporting their role in the energy transition.

# 2. Introduction

The global shift toward low-carbon, electric, mobility highlights the growing need to understand the true environmental performance of BEVs, especially as national power grids continue to decarbonize and battery production scales rapidly. Given that the transportation sector remains one of the largest contributors to greenhouse gas emissions worldwide, comparing BEVs with internal combustion engine (ICE) vehicles is essential for quantifying the potential emission reductions and identifying the associated environmental trade-offs across their entire life cycle.

Life cycle assessment (LCA) provides a robust framework for evaluating these impacts by accounting for all stages of a vehicle’s life, from raw material extraction and manufacturing to use-phase emissions and end-of-life treatment. Such a holistic approach is particularly important for BEVs, whose environmental performance is strongly influenced by electricity mix, battery chemistry, and assumptions about energy system evolution over time.

Against this backdrop, this study applies LCA methodology to systematically assess the environmental burdens of BEVs and ICE vehicles under different electricity scenarios. By integrating current research, realistic operational data, and forward-looking grid decarbonization pathways, the report aims to deliver evidence-based insights for researchers, policymakers, and industry stakeholders seeking to guide sustainable mobility strategies, inform regulatory decisions, and support technology development in the evolving automotive landscape.

## 3. Goal and Scope Definition

The goal of the study is to compare the full life cycle environmental impacts of BEVs and ICE vehicles, including BEV variations with different energy mix sources for charging, to support decisions related to sustainable transport and energy transition planning. The LCA applies a cradle-to-use-phase boundary and excludes end-of-life treatment processes such as dismantling, recycling, and disposal. The system includes raw material extraction, manufacturing, and use phase operation only. This is done because of inconsistent recycling datasets or limited relevance to the comparative goal. The assessment applies the ReCiPe 2016 Midpoint impact method and uses ecoinvent 3.x cutoff system model data. Assumptions include fixed lifetime, representative energy consumption, region-specific electricity mixes, and average battery chemistry. Allocation follows ecoinvent’s cutoff rules, and all methodological choices and limitations are documented to meet ISO requirements.

Tables 1 and 2 define the baseline assumptions and derived parameters used throughout the LCA to enable a consistent comparison between the BEV and ICE vehicle models. The first table outlines the key input assumptions - such as vehicle lifetime, driving distance, energy and fuel consumption, and battery characteristics - that form the foundation of both modelling approaches. The second table translates these inputs into calculated lifetime energy and fuel use indicators, which are subsequently integrated into the life-cycle inventory. Together, these tables establish a coherent and transparent parameter set that ensures comparability between the two vehicle types across the entire assessment.

Table 1. Assumed parameters for BEV and ICE models (Del Duce, Gauch and Althaus, 2016)

| Parameter | Value | Unit |
|---|---|---|
| Car Lifetime Years | 12 | years |
| Car Lifetime Distance Travelled | 150,000 | km |
| Battery Capacity | 60 | kWh |
| Battery Mass per kWh | 6 | kg per kWh |
| BEV Energy Consumption per 100 km | 18 | kWh per 100 km |
| Charging Efficiency | 90 | % |
| ICE Fuel Consumption per 100km | 6.5 | L per 100 km |
| Car Mass | 1,500 | kg |

Table 2. Calculated parameters for BEV and ICE models

| Parameter | Formula | Unit |
|---|---|---|
| Battery Mass | Battery Mass per kWh * Battery Capacity | years |
| BEV Lifetime Energy Use | BEV Energy Consumption per 100 km * Lifetime Distance Travelled / 100 | kWh |
| ICE Lifetime Fuel Consumption | ICE Fuel Consumption per 100km * Lifetime Distance Travelled / 100 | L |

# 4. Life Cycle Inventory (LCI) Analysis

Inventory data were obtained from ecoinvent 3.x datasets for vehicle manufacturing, powertrain components, battery production, electricity supply, and fuel pathways, supplemented with literature-based parameters for battery mass and recovery rates. BEV models incorporate electricity mix scenarios representing different national grids, while ICE models include gasoline production and combustion emissions. Vehicle and battery masses, energy consumption rates, and recycling fractions were parameterized in openLCA 2.5 for efficient scenario testing.

Figures 1–3 collectively illustrate how the LCA models for the BEV and ICE vehicles were structured and implemented. **Figure 1** establishes the overarching system boundary applied to both vehicle types, covering the full cradle-to-grave life cycle. This boundary includes shared stages—such as raw material extraction, vehicle manufacturing, use phase, and end-of-life—as well as the energy-supply chains specific to each technology: electricity generation for the BEV and fuel production for the ICE vehicle.

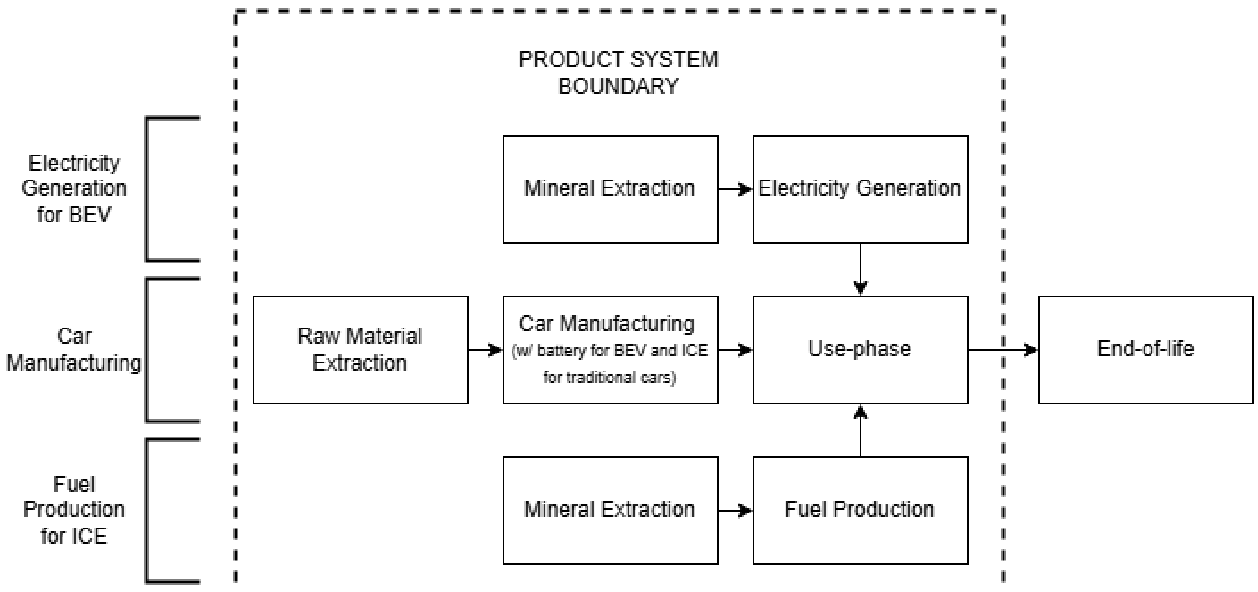


Figure 1. System Boundary for the LCAs

Building on this system definition, **Figure 2** visualizes how the BEV life cycle is translated into a process structure within OpenLCA. The model integrates the key upstream processes identified in the boundary—battery manufacturing, electricity supply for the use phase, and electric vehicle production—showing how these flows combine to represent one BEV over its entire lifetime.

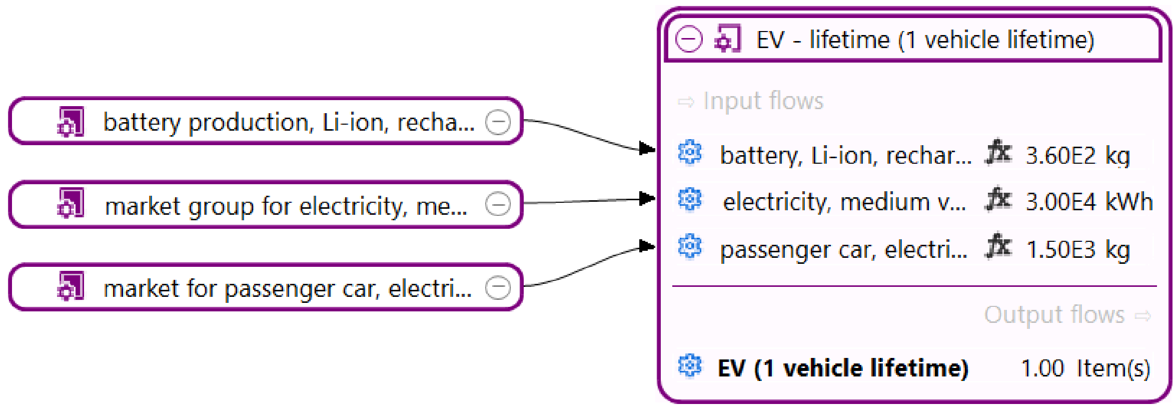


Figure 2. Model graph of BEV in OpenLCA

Similarly, **Figure 3** shows the corresponding OpenLCA model for the ICE vehicle, reflecting the system boundary by incorporating vehicle manufacturing and the petroleum refining process needed to supply lifetime fuel demand. Together, the three figures demonstrate the consistency between the conceptual system boundary and its practical implementation in OpenLCA, ensuring that both vehicle models are built on parallel, comparable structures.

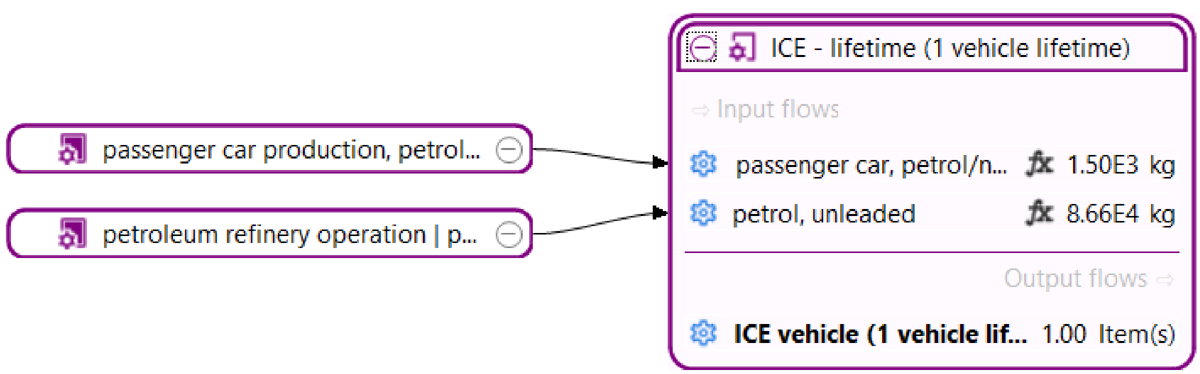


Figure 3. Model graph of ICE in OpenLCA

# 5. Life Cycle Impact Assessment (LCIA)

The LCIA was performed using the ReCiPe 2016 Midpoint (H) method covering climate change, fossil resource scarcity, mineral resource scarcity, particulate matter formation, human toxicity, and water consumption. Characterization factors were applied without normalization or weighting, consistent with ISO guidelines. EV results were evaluated for multiple electricity mixes, while ICE results were based on standard fuel combustion datasets. The electricity mixes investigated in this study consists of France, Germany, and Hungary as these countries have very different energy mixes. The assessment quantifies both upstream impacts of vehicle and battery manufacturing and downstream impacts of energy use, enabling a comprehensive comparison across technologies and scenarios.

# 6. Results

The environmental impacts of different energy mixes were investigated. In this study, France, Germany, and Hungary were considered for their variety of energy sources. For a comparative analysis of car manufacturing and use phases of BEV and ICE, the following environmental impacts were explored: (a) fine particulate matter, (b) fossil resource recovery, (c) global warming, (d) mineral resource scarcity, (e) human carcinogenic toxicity, (f) human non-carcinogenic toxicity and (g) water consumption. As seen in Figure 4, France generally had the lowest impacts calculated. This is attributed to the use of nuclear energy in the majority of its energy mix. However, because of the use of rare earth minerals in nuclear power production, France's energy mix has high impacts on mineral resource scarcity. In the following investigations on BEV and ICE life cycles, the assumed electricity provider for charging the electric vehicles will be based on France's energy mix.

Results show that BEVs exhibit significantly lower climate change impacts than ICE vehicles when charged with electricity mixes of low carbon intensity such as in France's case, although BEVs have higher mineral and metal resource depletion impacts due to battery manufacturing. Electricity resources increase EV production impacts but have diminishing influence on cradle-to-use-phase results when clean electricity is used. In Figure 5, contribution analysis reveals that car and battery manufacturing dominates EV production impacts, while fuel combustion dominates ICE impacts as shown in Figure 6. Electricity mix is the strongest driver of EV use-phase emissions, with renewable-rich grids reducing lifecycle GWP by up to 70% compared to fossil-heavy grids.

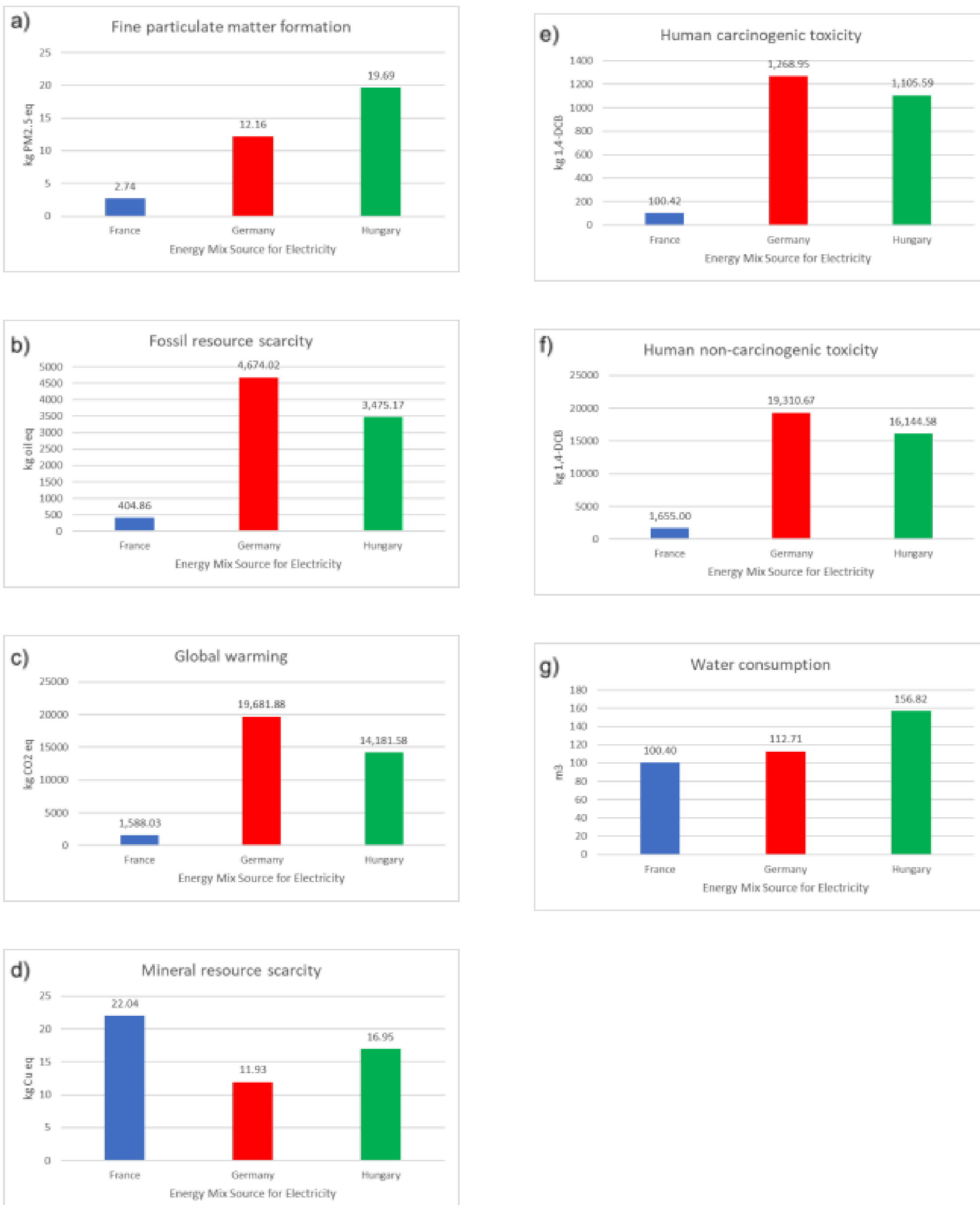


Figure 4. Environmental impact of different energy mixes

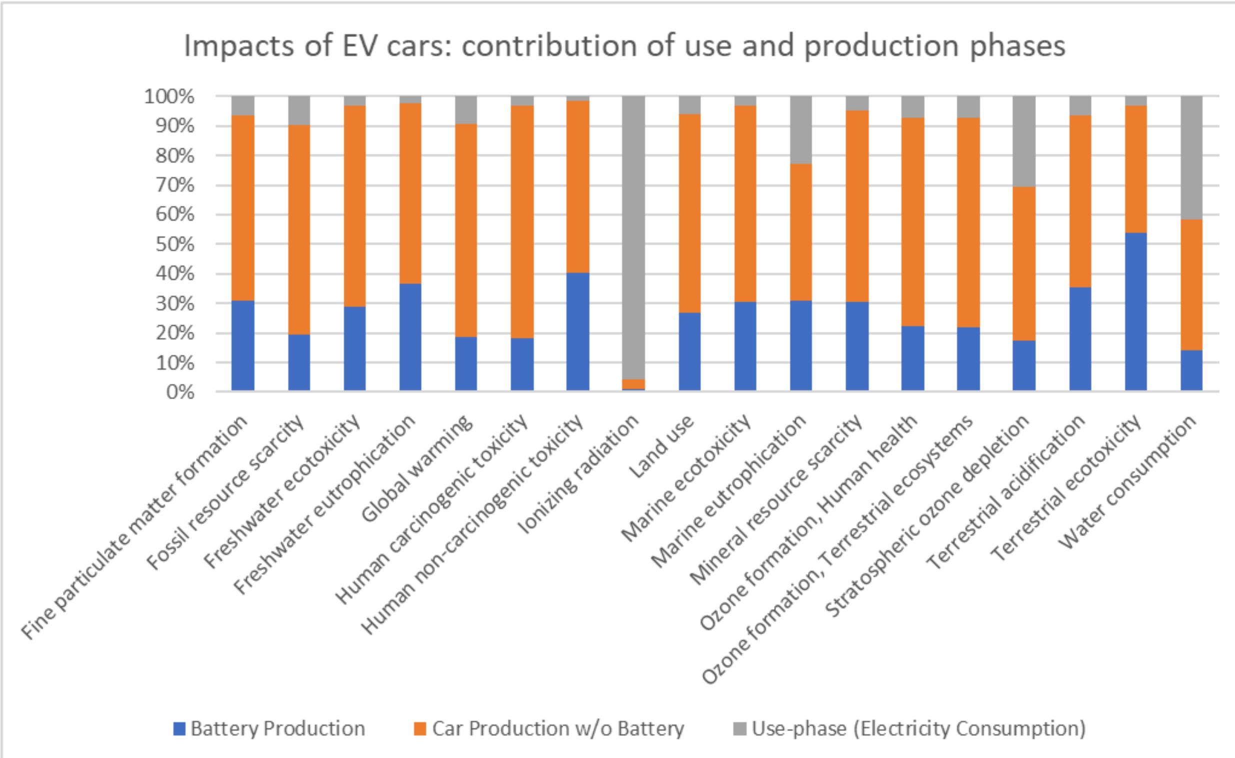


Figure 5. Environmental impact contributions of different phases of BEV life cycle

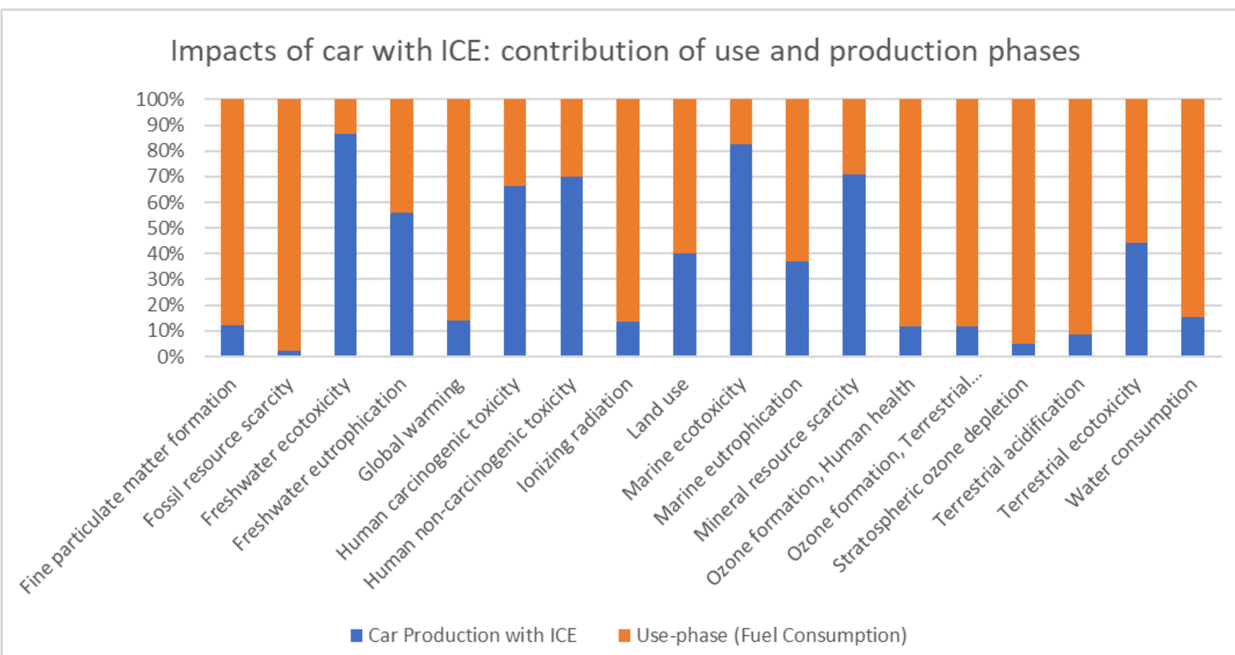


Figure 6. Environmental impact contributions of different phases of ICE life cycle

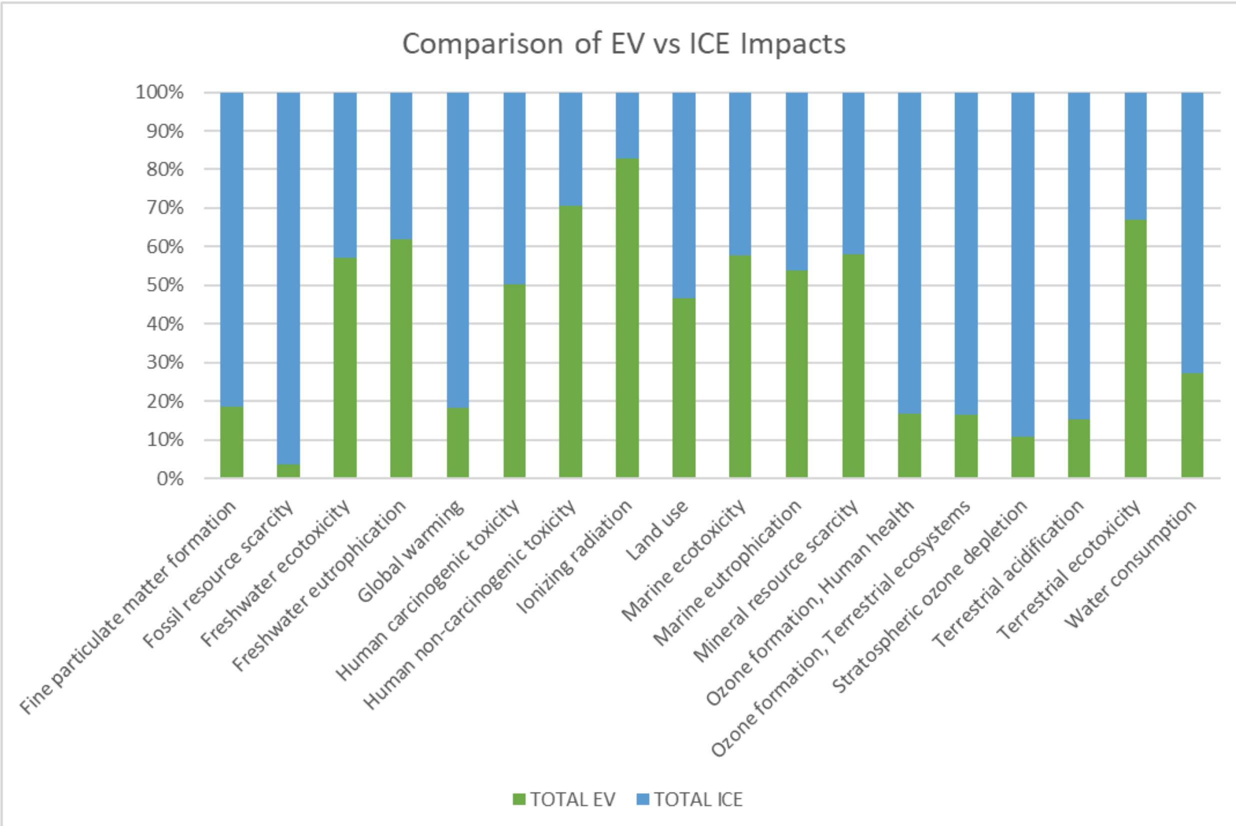


Figure 7. Comparison of BEV and ICE Impacts

In this study, ICE vehicles have a noticeably larger impact on the environment when compared to BEVs (see Figure 7). Specifically, high fine particulate matter formation and global warming contribution during the combustion of petroleum-derived fuels, fossil resource scarcity from oil extraction, and water consumption attributed to both oil extraction and refining. On the other hand, the use of EVs with a primarily nuclear power-based energy mix have higher calculated human health impacts, marine and terrestrial ecotoxicity, and ionizing radiation.

## 7. Interpretation

The interpretation identifies the electricity mix and car manufacturing as the most influential factors shaping vehicle LCA outcomes. EVs consistently outperform ICE vehicles in climate change impacts when charged using moderate- to low-carbon electricity, confirming their long-term advantage under energy transition pathways. High mineral resource impacts suggest the need for improved battery chemistries, material efficiency, and recycling technologies. Limitations include data uncertainty for emerging technologies, regional variability in material production, and assumptions regarding vehicle lifetimes. Despite uncertainties, the findings are robust across sensitivity analyses, supporting the conclusion that EVs provide substantial environmental benefits as power grids decarbonize. Future developments on making nuclear-based energy mixes safer for human health should also be considered in planning.

## 8. References

This study relies on openLCA 2.5, the ecoinvent 3.x database, ReCiPe 2016 LCIA method documentation, peer-reviewed literature on Li-ion battery production and recycling, national electricity mix statistics, and established sources for vehicle mass, fuel consumption, and operational parameters. All datasets, parameters, and methodological sources adhere to ISO documentation requirements.

Main Academic Papers for References

Del Duce, A., Gauch, M., & Althaus, H.-J. (2016). Electric passenger car transport and passenger car life cycle inventories in ecoinvent version 3. The International Journal of Life Cycle Assessment, 21(10), 1314–1326. https://doi.org/10.1007/s11367-014-0792-4 Springer Link

Cappelli, A., Trimarchi, N. S., Marzeddu, S., Paoli, R., & Romagnoli, F. (2025). A comparative life cycle assessment of an electric and a conventional mid-segment car: Evaluating the role of critical raw materials in potential abiotic resource depletion. Energies, 18(14), 3698. https://doi.org/10.3390/en18143698