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Electric vs. Internal Combustion Vehicles: A Multi-Regional Life Cycle Assessment Comparison for Environmental Sustainability

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***Abstract* – The growing concern for environmental sustainability has sparked a shift towards electric vehicles as a more environmentally friendly alternative to internal combustion engine vehicles (ICEVs). This review paper comprehensively incorporates a wide range of Life Cycle Assessment (LCA) studies to conduct a detailed comparison of the environmental impact of battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEV) in different regions and under various scenarios. The analysis encompasses recent research from various years and diverse locations, such as the USA, Spain, Poland, Germany, the Czech Republic, China, and Japan. The LCA evaluations yield significant insights into the global warming potential (GWP) represented by CO_2 equivalent emissions per vehicle kilometre over their lifespan. The findings also emphasize that BEVs charged with renewable energy offer greater environmental benefits than biofuel-driven cars. Furthermore, the study incorporates various future scenarios, such as the widespread adoption of renewable energies, which could lead to substantial reductions in CO_2eq emissions. However, the comparative analysis reveals varying impacts for BEVs in different regions, particularly highlighting the importance of the electricity mix used to charge BEV batteries. Overall, the review paper serves as a valuable contribution to the broader aim of understanding transport drivetrain implications on environment. Integrating diverse LCA assessments can inform sustainable transportation policies and practices.**

***Keywords* – Automotive industry; battery electric vehicles; climate change; internal combustion engine vehicles; LCA.**

1. INTRODUCTION

The transportation sector is a major contributor to greenhouse gas emissions and air pollution, posing a significant threat to the environment and public health [1]. The introduction of electric vehicles has been presented as a promising solution [2], [3], specifically, battery electric vehicles (BEVs) have gained significant attention and support from governments, researchers, and consumers due to their potential to reduce CO_2 emissions [4], dependence on fossil fuels [5], and cost of ownership [6]. Furthermore, electric vehicles offer the added benefit of local emission reductions, improving air quality and public health, especially in urban areas [7]–[9]. However, the true environmental footprint of BEVs remains a subject of debate, with factors such as the source of electricity, battery production, and vehicle lifespan playing crucial roles.

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As the awareness of the true carbon footprint of cars increases with the understanding that cars are emitting much more than official datasheets are portraying them to do [10] it is even more pressuring to evaluate the life cycle of cars. At the same time, with the increase in the adoption of BEVs [11], growing concerns about their true environmental footprint have emerged [12]. It is crucial to consider regional perspectives and local factors [13] when evaluating the environmental impact of BEVs compared to ICEVs [14].

While numerous studies have explored the environmental benefits of BEVs [15]–[19], a comprehensive and comparative analysis across different regions and future scenarios is still needed. This study aims to address this gap by conducting a comprehensive review of Life Cycle Assessments (LCA) to evaluate the environmental impact of BEVs and Internal Combustion Engine Vehicles (ICEVs) under various conditions. By considering factors such as the electricity mix, battery production, and end-of-life scenarios, this research seeks to provide a more accurate assessment of the environmental performance of these two vehicle types.

While the environmental benefits of BEVs are often touted, the impact of regional electricity sources on their overall carbon footprint remains understudied. This research seeks to fill this gap by comparing the environmental performance of BEVs and ICEVs across different regions. The study will assess the potential for BEVs to significantly reduce greenhouse gas emissions by analysing future energy scenarios.

This paper conducts a comprehensive review of multiple LCAs to evaluate the global warming potential, measured in CO_2 equivalent emissions per vehicle kilometre over the lifespan, of Battery Electric Vehicles (BEVs) and Internal Combustion Engine Vehicles (ICEVs). By incorporating diverse LCA studies from various regions, including the USA, Spain, Poland, UK, Germany, China, Japan, and the Czech Republic, the analysis highlights the varying environmental impacts of BEVs in different contexts. The study emphasizes the crucial role of electricity sources in determining the environmental benefits of BEVs, exploring the impact of different energy mixes and the potential for significant CO_2 reductions through the widespread adoption of renewable energy sources.

The findings of this study will contribute to a better understanding of the environmental implications of BEV adoption and inform the development of sustainable transportation policies and strategies.

2. METHODOLOGY

This paper employed a rigorous methodology to comprehensively assess the environmental impact of BEVs compared to internal combustion engine vehicles (ICEVs). This involved conducting a systematic review and analysis of existing Life Cycle Assessment (LCA) studies. These studies encompassed research from a diverse range of regions, including the USA, Spain, Poland, Germany, China, Japan, and the Czech Republic.

The selected LCAs covered the entire life cycle of both BEVs and ICEVs, meticulously examining factors such as vehicle production and manufacturing processes, the energy sources used for charging electric vehicles, battery production and disposal practices, real-world vehicle operation with its associated energy consumption, and even potential end-of-life scenarios for both vehicle types.

This comprehensive approach allowed for a robust comparative analysis that evaluated the environmental impact of BEVs and ICEVs across different geographic contexts and operational scenarios. Furthermore, the analysis specifically focused on a critical environmental indicator – global warming potential. This metric, measured in CO_2 equivalent emissions per vehicle kilometre over the lifespan of the vehicles, provided a clear and quantifiable basis for comparing the environmental footprints of BEVs and ICEVs.

By employing this multifaceted methodology, the paper aimed to shed light on the true environmental implications of electric mobility, offering valuable insights for informed decision-making towards a more sustainable transportation future.

The selection criteria for the Life Cycle Assessment studies included in this analysis (listed in Table 1) were defined to ensure the comprehensive coverage of factors influencing the environmental impact of battery electric vehicles and internal combustion engine vehicles.

TABLE 1. LIST OF LCA STUDIES USED IN THIS PAPER

Article No.	**Title**	**Publishing journal**	**Year of publishing**
1	Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions [20]	Sustainability	2020
2	Comparative life cycle assessment of conventional, electric and hybrid passenger vehicles in Spain [21]	Journal of Cleaner Production	2021
3	Environmental life cycle assessment of electric vehicles in Poland and the Czech Republic [22]	Journal of Cleaner Production	2018
4	Accurate energy consumption for comparison of climate change impact of thermal and electric vehicles [23]	Energy	2023
5	No Doubt About It: EVs Really Are Cleaner Than Gas Cars [24]	BloombergNEF	2024
6	The Environmental Footprint of Transport by Car Using Renewable Energy [25]	Earth's Future	2020

The following criteria were applied to identify relevant LCA studies:

1. Publication Date: LCA studies considered for inclusion were conducted in recent years (2018–present) to capture the most current data and reflect the latest developments in technology, energy sources, and environmental regulations.
2. Type of Vehicle: The analysis encompassed LCA studies focused on both BEVs and ICEVs to enable a comparative evaluation of their environmental impact.
3. Geographic Coverage: The inclusion of LCA studies conducted in various regions was essential to capture the geographical variations in energy sources, manufacturing processes, and transportation infrastructure. This approach facilitated a nuanced understanding of the environmental implications of EVs and ICEVs in diverse operational contexts (Fig. 1).
4. Scope of Analysis: LCA studies with a holistic scope, encompassing all stages of the vehicles' life cycles from production to end-of-life management, were prioritized. This criterion ensured that the selected studies provided a comprehensive assessment of environmental impacts, including factors such as vehicle manufacturing, energy sources for charging, battery production, vehicle operation, and disposal.

By integrating LCA studies ([20]–[25]) that align with these selection criteria, this analysis aims to offer a robust and multi-faceted perspective on the environmental performance of BEVs and ICEVs. The inclusion of diverse studies meeting these criteria enhances the comprehensiveness and reliability of the comparative evaluation, ultimately contributing to the informed understanding of sustainable transportation options and policies.

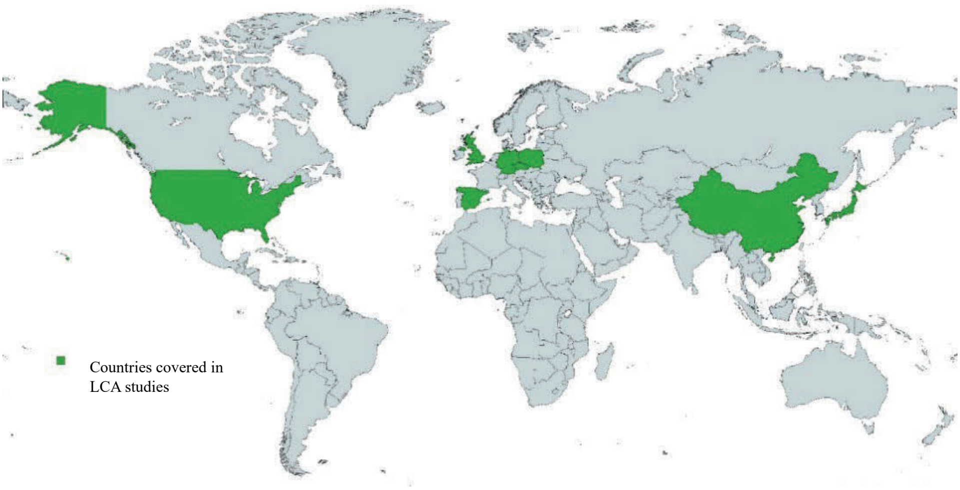

Fig. 1. A map view of countries covered in selected LCA studies.

3. RESULTS AND DISCUSSION

The comparative analysis of Life Cycle Assessment findings from various regions and scenarios offers valuable insights into the environmental impact of battery electric vehicles and internal combustion engine vehicles, see Table 2.

TABLE 2. KEY FINDINGS OF THE SELECTED LCA STUDIES

Article No.	Regional coverage	Key findings
1	Europe	Under optimized conditions, electric cars can compete well in terms of CO_2eq emissions per passenger kilometre with other traffic modes (diesel bus, coach, trains) over a lifetime. Energy used in the production of batteries plays a major role in terms of LCA.
2	Spain (Europe)	In Spanish scenario, BEVs' life cycle CO_2eq emissions are 48 % lower than petrol ICEVs'. Future scenarios would lead to a 19.26 % and 27.41 % decrease in CO_2eq emissions in 2030 and 2050, respectively. Transfer of environmental burdens from the use phase to the raw materials extraction and manufacturing phases entails a delocalization of the impacts, which constitutes a new challenge at environmental, social, and legal levels.
3	Poland, Czech Republic (Europe)	Greenhouse gas emissions and fossil fuels depletion of EVs (currently and in the future) are lower than those of ICEVs in both Poland and the Czech Republic. An EV has the lowest environmental indicators for all impact categories when hydropower is used for electricity production for charging EV batteries.
4	Europe	The results show a lower GWP for EVs, relative to ICEVs. This work highlights the importance of considering real driving cycles instead of relying on traditional standard cycles and the manufacturer-reported data.
5	USA, Germany, UK, China, Japan	In all analysed cases, EVs have lower lifecycle emissions than ICEVs. Results depend on estimated lifetime and the cleanliness of the electricity where they charge.
6	USA (North America)	Results show that solar-powered BEVs have the smallest environmental footprints per kilometre, while biofuel-ICEVs have the largest footprints. Switching from ICEV to BEV gives an emission saving per km of 96 % in the case of bioelectricity and 100 % in the case of solar electricity. A solar-based BEV or fuel-cell electric vehicle (FCEV) has an order of magnitude smaller land footprint than a bio-based vehicle.

One of the key findings relates to the global warming potential, measured in CO_2 equivalent emissions per vehicle kilometre over the lifespan of the vehicles. As described in Table 2 and Table 3, the analysis revealed that BEVs generally have significantly lower well-to-wheel CO_2 emissions compared to ICEVs, especially in regions where electricity generation is less carbon-intensive.

TABLE 3. KEY FACTORS AND RESULTS OF THE SELECTED LCA STUDIES

Article No.	Used database and LCA method	Analysed vehicles	Production origin	Use phase	LCA Climate change results
1	Database: *Ecoivent* (2.2, 3.0), Real-world close emission values LCA method: Cradle-to-grave + Well-to-wheel, ReCiPe (2012)	ICEV: 2016 VW Caddy BEV: 2016 VW Caddy electrified	Mostly Europe, batteries in China	Vehicle lifetime: 150 000 km, 200 000 km Electricity origin: DE 2013, DE 2050, PV, Wind	ICEV: 263-274 CO_2e g/km BEV: 73-308 CO_2e g/km
2	Database: Zijlema (2018), Holmatov *et al.* (2019), USDOE (2019a) LCA method: Well-to-wheel	ICEV: 2019 Kia Forte FE, 2019 Toyota Camry, 2019 Chevrolet Cruz Hatchback, 2016 Mercedes-Benz E350, BEV: 2019 Honda Clarity EV, 2019 Nissan Leaf	N/A	Km per year: 21 687 km Electricity origin: Bioelectricity, PV	ICEV: 80.2-185 CO_2e g/km BEV: 0-7.3 CO_2e g/km
3	Database: *Ecoinvent* (3.5) LCA method: Cradle-to-grave + Well-to-wheel	ICEV: VW Golf VII (gasoline, diesel) BEV: BMW i3 (BEV, 120Ah)	Europe	Vehicle lifetime: 150 000 km Electricity origin: SP 2014-2018 SP 2030 SP 2050	ICEV: 241-261 CO_2e g/km BEV: 98-141 CO_2e g/km
4	Database: *Ecoinvent* (3.0) LCA method: Cradle-to-grave + Well-to-wheel, ReCiPe, Midpoint, LCIA	ICEV: Theoretical 1.4L 1200kg vehicle BEV: 2010 Nissan Leaf	Not specified	Vehicle lifetime: 150 000 km Electricity origin: PL & CZ 2015 PL & CZ 2050	ICEV: 284 CO_2e g/km BEV PL: 81-276 CO_2e g/km BEV CZ: 81-214 CO_2e g/km
6	Database: BloombergNEF, EPA, ICCT LCA method: Cradle-to-grave + Well-to-wheel	ICEV: Theoretical mid-sized car BEV: Theoretical mid-sized car	USA, UK, Germany, China, Japan (cars are made locally)	Vehicle lifetime: 250 000 km Electricity origin: Local electricity over the lifetime of the vehicle	ICEV: 112-304 CO_2e g/km BEV: 4-116 CO_2e g/km
5	Database: Other research, Energetic Macroscopic Representation formalism LCA method: Cradle-to-grave + Well-to-wheel	ICEV: 2018 Renault Clio III BEV: 2018 Renault Zoe	Asia + France	Vehicle lifetime: 150 000 km Electricity origin: EU	ICEV: 198-219 CO_2e g/km BEV: 140 CO_2e g/km

However, the environmental performance of BEVs is highly dependent on the manufacturing part of the lifecycle, emphasizing the significance of the production of batteries.

By integrating findings from diverse LCA studies, this analysis offers a multi-faceted perspective on the environmental performance of BEVs and ICEVs, highlighting the complex interplay of factors that influence their environmental footprint across different regions and scenarios.

One of the common conclusions is that the environmental performance of BEVs is significantly influenced by the source of electricity used for charging. In regions where electricity generation is primarily based on fossil fuels, like Poland, the overall carbon footprint of BEVs can be higher compared to areas with a higher share of renewable energy sources in the electricity mix, like United Kingdom. A BEV that is charged in Poland in today's electricity mix could be responsible of lifetime 39 metric tons CO_2e, while a similar BEV that is charged in Check Republic would yield 32 metric tons of CO_2e. Even further reduction is noticeable in UK where a BEV could account for 8 metric tons of CO_2e, while having a lifecycle that is almost double as long. This underlines the importance of transitioning towards renewable energy to maximize the environmental benefits of BEVs.

All studies show that the manufacturing of batteries for electric vehicles have significant environmental implications, particularly concerning resource extraction, energy consumption, and emissions associated with battery production. Assessing the environmental performance of BEVs requires considering the varying environmental standards and practices in different regions where batteries and other parts of cars are produced.

Closely related to battery manufacturing is the size and composition of batteries in BEVs. These play a critical role in determining their environmental impact. Larger batteries, while offering an increased driving range, show more energy-intensive production processes. Additionally, considerations regarding the end-of-life management of batteries and the recycling or disposal processes also contribute to the overall environmental footprint of BEVs.

A key role is driving patterns and the lifetime of the vehicle. Factors such as energy consumption during vehicle operation, and maintenance requirements contribute to the overall sustainability of electric mobility. Assessing the environmental performance of BEVs requires considering their operational efficiency and durability over their entire lifecycle.

The environmental performance of both BEVs and ICEVs is influenced by their respective manufacturing processes and the location it is taking place. The energy consumption, emissions, and resource utilization during vehicle production differ between the two technologies, influencing their overall environmental impact. Understanding the differences in manufacturing processes is essential for comprehensive comparisons of the environmental performance of BEVs and ICEVs.

The environmental performance of BEVs and ICEVs is contingent on a multitude of determinants, each of which warrants careful consideration in evaluating the sustainability of electric mobility.

4. CONCLUSIONS

The review paper highlights the significant potential of BEVs to reduce environmental impact compared to ICEVs, particularly in the context of increased renewable energy adoption. It emphasizes how a shift towards renewable energy sources in the electricity mix holds the promise of substantially reducing well-to-wheel CO_2 emissions for BEVs, contributing to the mitigation of global warming potential.

However, the paper also underscores the importance of considering regional variations and the electricity mix when evaluating the environmental performance of BEVs. It emphasizes the need to assess factors such as driving patterns, manufacturing processes, and the size and composition of batteries, as these determinants have a profound impact on the overall sustainability of electric mobility.

Additionally, the transition to greater renewable energy adoption may lead to a decrease in the carbon intensity associated with battery production, thereby contributing to the overall sustainability of electric vehicle manufacturing.

This paper does not reflect the optimization potential of manufacturing practices, more efficient part usage, or use-case optimization, which can contribute to the improvement of the overall life cycle of vehicles. By addressing these aspects, BEVs can evolve into a truly sustainable transportation solution. Furthermore, comprehensive comparisons require a thorough understanding of the environmental impact of both BEV and ICEV manufacturing processes across different regions.

This analysis underscores the complexity of environmental considerations in electric mobility. A multifaceted approach that considers the entire lifecycle of BEVs and ICEVs, along with regional variations, is crucial for informed decision-making towards sustainable transportation. Overall, the review paper underscores the promising prospects for enhancing the environmental performance of BEVs through the acceleration of renewable energy adoption, marking a significant step towards a greener and more sustainable transportation ecosystem.

REFERENCES

[1] Buekers J., Holderbeke M. V., Bierkens J., Buekers J. Health and environmental benefits related to electric vehicle introduction in EU countries. *Transportation Research Part D: Transport and Environment* 2014:33:26-38. https://doi.org/10.1016/j.trd.2014.09.002

[2] Bicer Y., Dincer I. Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles. *Resources, Conservation and Recycling* 2018:132:141–157. https://doi.org/10.1016/j.resconrec.2018.01.036

[3] Togun H. *et. al.* A review on recent advances on improving fuel economy and performance of a fuel cell hybrid electric vehicle. *International Journal of Hydrogen Energy* 2024:89:22–47. https://doi.org/10.1016/j.ijhydene.2024.09.298

[4] Ricardo Energy & Environment. Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA. European Commission: Brussels, 2020.

[5] IEA, World Energy Outlook 2024. IEA: Paris, 2024.

[6] Ricardo Energy & Environment. Assessing the impacts of selected options for regulating CO_2 emissions from new passenger cars and vans after 2020. European Commission: Brussels, 2018.

[7] Johnston J., McConnell R., Palinkas L., Garcia E., Eckel S. P. California's early transition to electric vehicles: Observed health and air quality co-benefits. *Science of The Total Environment* 2023:867:161761. https://doi.org/10.1016/j.scitotenv.2023.161761

[8] Karabasoglu O., Michalek J. Influence of driving patterns on life cycle cost and emissions of hybrid and plug-in electric vehicle powertrains. *Energy Policy* 2013:6:445–461. https://doi.org/10.1016/j.enpol.2013.03.047

[9] Suganya R., Joseph L. L., Sreedhar K. Understanding lithium-ion battery management systems in electric vehicles: Environmental and health impacts, comparative study, and future trends: A review. *Results in Engineering* 2024:24. https://doi.org/10.1016/j.rineng.2024.103047

[10] Morales V. V., Tietge U., Dornoff J. On the way to 'real-world' CO_2 values? The European passenger car market after 5 years of WLTP. International Council on Clean Transportation Europe Jan. 30, 2024.

[11] BloombergNEF. Zero-Emission Vehicles Factbook. A BloombergNEF special report prepared for COP28, 2023.

[12] Transport & Environment. Clean and lean. Battery metals demand from electrifying passenger transport. European Federation for Transport and Environment AISBL, 2023.

[13] European Environment Agency. Use of renewable energy for transport in Europe, 2024.

[14] Bieker G. A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars. International Council on Clean Transportation, 2021.

[15] Qiao Q., Zhao F., Liu Z., Hao H., H Xin., Przesmitzki S. V., Amer A. A. Life cycle cost and GHG emission benefits of electric vehicles in China. *Transportation Research Part D: Transport and Environment* 2020:86:102418. https://doi.org/10.1016/j.trd.2020.102418

[16] Ayodele B., Mustapa S. Life Cycle Cost Assessment of Electric Vehicles: A Review and Bibliometric Analysis. *Sustainability* 2020:12(6):2387. https://doi.org/10.3390/su12062387

[17] Zheng G., Peng Z. Life Cycle Assessment (LCA) of BEV's environmental benefits for meeting the challenge of ICExit (Internal Combustion Engine Exit). *Energy Report* 2021:7:1203–1216. https://doi.org/10.1016/j.egyr.2021.02.039

[18] Scedrovs A., Mendzins K., Barisa A., Feofilovs M. Electrifying the Last Mile Delivery by Eco-Efficiency Analysis: Case Study of Latvia. *Environmental and Climate Technologies* 2024:28(1):367–378. https://doi.org/10.2478/rtuect-2024-0029

[19] Hauschild M. Z., Rosenbau R. K., Olsen S. I. Life cycle assessment, Springer International Publishing, 2018.

[20] Johannes D., Weiss M., Helmers E. Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions. *Sustainability* 2020:12(3):1241. https://doi.org/10.3390/su12031241

[21] Bolonio D., Ortega M. F., Garcia-Martinez M.-J., Naranjo G. P.-S. Comparative life cycle assessment of conventional, electric and hybrid passenger vehicles in Spain. *Journal of Cleaner Production* 2021:291:125883. https://doi.org/10.1016/j.jclepro.2021.125883

[22] Burchart-Korol D., Jursova S., Korol J., Pustejovska P., Blaut A. Environmental life cycle assessment of electric vehicles in Poland and the Czech Republic. *Journal of Cleaner Production* 2018:202:476–487. https://doi.org/10.1016/j.jclepro.2018.08.145

[23] Desreveaux A., Bouscayrol A., Trigui R., Hittinger E., Castex E., Sirbu G. M. Accurate energy consumption for comparison of climate change impact of thermal and electric vehicles. *Energy* 2023:268:126637. https://doi.org/10.1016/j.energy.2023.126637

[24] Cantor C. No Doubt About It: EVs Really Are Cleaner Than Gas Cars. BloombergNEF, 2024.

[25] Hoekstra A. Y., Holmatov B. The Environmental Footprint of Transport by Car Using Renewable Energy. *Earth's Future* 2020:8(2):e2019EF001428. https://doi.org/10.1029/2019EF001428