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Life Cycle Assessment of Electric Vehicles vs. Internal Combustion Engine Vehicles: A Post-2020 Comparative Analysis

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Abstract—The rapid electrification of transportation after 2020 has increased discussions about whether electric vehicles (EVs) are more environmentally friendly than internal combustion engine vehicles (ICEVs). Although EVs do not produce tailpipe emissions, their total impact on the environment depends on the manufacturing process, battery production, the combination of electricity production, and end-of-life treatment. In this work, the LCA of EVs and ICEVs on the basis of cradle-to-grave life cycle analysis is provided under the conditions of technological progress and the grid in the post-2020 period, with references to the Indian electricity mix. Mathematical emission modeling, break-even analysis, and sensitivity analysis are conducted for a functional unit of 150,000 km. Results indicate that EVs exhibit higher manufacturing emissions but lower operational emissions. Compared to ICEVs, EVs exhibit 6–30% lower total life cycle emissions under current grid conditions (0.7 kg CO_2/kWh). The study also emphasizes how important grid decarbonization is to improving EV sustainability performance.

Keywords—*Electric Vehicles, Life Cycle Assessment, Internal Combustion Engine Vehicles, Carbon Emissions, Battery Manufacturing, Well-to-Wheel Analysis.*

I. INTRODUCTION

The transportation sector is responsible for roughly 24% of global energy-associated CO_2 emissions [1]. Road transport represents the dominant share of this contribution due to widespread reliance on fossil fuel-powered vehicles. In response to global climate commitments and regulatory pressures, electric vehicle adoption has accelerated significantly since 2020 [2].

Although EVs eliminate direct tailpipe emissions, a complete environmental assessment must evaluate them throughout their life cycle. LCA assesses raw material extraction to end-of-life disposal environmental impacts [3].

Using a cradle-to-grave LCA framework, this study compares EVs and ICEVs in post-2020 technological environments.

II. REVIEW OF LITERATURE

Recent studies after 2020 have significantly refined “Life Cycle Assessment (LCA)” methodologies for comparing “Electric Vehicles (EVs)” and “Internal Combustion Engine Vehicles (ICEVs)”. Previous studies had a tendency to underestimate grid dependency and battery production emissions. The literature after 2020 includes new battery production data, local electricity composition, and recycling possibilities.

A. Global Life Cycle Emission Comparisons

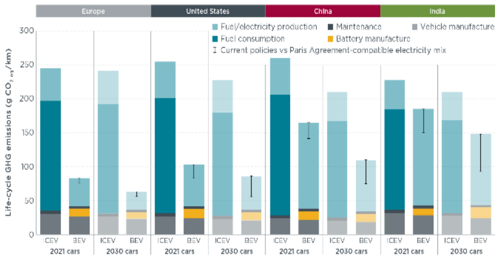
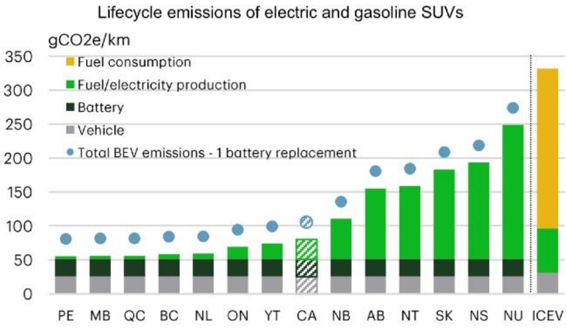
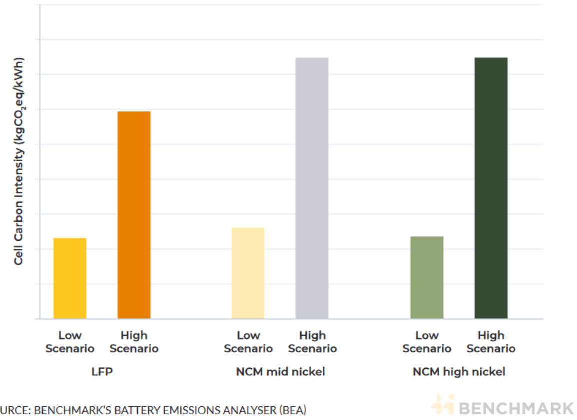


Figure ES.1. Life-cycle GHG emissions of average medium-size gasoline internal combustion engine (ICEVs) and battery electric vehicles (BEVs) registered in Europe, the United States, China, and India in 2021 and projected to be registered in 2030. The error bars indicate the difference between the development of the electricity mix according to stated policies (the higher values) and what is required to align with the Paris Agreement.



Note: Regional breakdown represents emissions for electric vehicles, the stacked column is EV with no battery replacement and the dot is EV with one battery replacement.
Sources: Argonne National Laboratory's GREET Model, National Renewable Energy Laboratory, Environment and Climate Change Canada, Statistics Canada, Natural Resources Canada, TD Economics.

Switching to renewable electricity can lower carbon intensities by as much as 40%



SOURCE: BENCHMARK'S BATTERY EMISSIONS ANALYSER (BEA)

Hawkins et al. and subsequent updates in European Commission Joint Research Centre (JRC) reports (2020–2023) demonstrated that EV lifecycle emissions are 30–70% lower than ICEVs in renewable-rich grids [1], [2]. These studies emphasized that electricity carbon intensity strongly influences total emissions.

The "International Council on Clean Transportation (ICCT)" (2022) reported that medium-sized battery electric vehicles in Europe emit 60–69% fewer lifecycle emissions compared to gasoline vehicles over 200,000 km [3].

But the ICCT study also pointed out that between 30 and 40 percent of the emissions from EV manufacturing come from the production of batteries.

B. Battery Manufacturing and Carbon Intensity

Ellingsen et al. (2020) and subsequent analyses in Nature Energy (2022–2024) evaluated lithium-ion battery production footprints and reported emission intensities ranging from 60–100 kg CO_2/kWh that depend on manufacturing location and energy source [4], [5].

Recent studies show:

- Chinese battery production has higher embodied carbon due to coal-based electricity.
- European gigafactories powered by renewables reduce battery footprint by 40%.

Dunn et al. (Argonne National Laboratory, 2022 GREET model updates) refined emission factors using updated cell chemistry and supply chain data [6].

C. Indian Context and Emerging Markets

India-specific LCA studies gained prominence after 2020.

TERI (2023) reported that EV lifecycle emissions in India are approximately 15–25% lower than those of ICE vehicles under current grid conditions (0.7 kg CO_2/kWh) [7].

IIT Bombay (2024) demonstrated that as India increases its renewable share to 50%, EV emission reduction improves to nearly 45% [8].

These studies confirm that grid decarbonization is the dominant variable.

D. Well-to-Wheel and Break-Even Analysis

Bieker (2021) emphasized break-even distance analysis, estimating that EVs in Europe offset higher manufacturing emissions after 30,000–60,000 km, depending on battery size [9].
In coal-heavy grids, break-even distances exceed 100,000 km.
Recent IEEE Transactions on Transportation Electrification (2023–2025) incorporate dynamic grid modeling and real-world driving cycles for more accurate estimation [10].

E. End-of-Life and Recycling Studies

Harper et al. (2021) and Gaines (2023) showed that battery recycling can reduce lifecycle emissions by 20–30% by recovering lithium, cobalt, and nickel [11], [12].

Second-life battery applications further reduce the total environmental burden.

F. Identified Research Gaps

The following gaps are found in the reviewed literature:
1. Limited India-focused cradle-to-grave analysis using post-2022 grid data.
2. Insufficient break-even modeling for Indian vehicle usage patterns.
3. Need for updated battery manufacturing emission factors.
4. Lack of integrated sensitivity modeling under renewable transition scenarios.

This study addresses these gaps by:
- Using updated Indian grid emission factor (0.7 kg/kWh).
- Incorporating 150,000 km functional unit.
- Performing break-even and sensitivity modeling.
- Comparing renewable-rich and coal-dominant scenarios.

G. Literature Summary Table

Author	**Year**	**Region**	**Key Finding**
JRC Report	2021	Europe	EVs have 30–70% lower emissions

ICCT	2022	Europe	60% lifecycle reduction
Ellingsen et al.	2020	Global	60–100 kg CO_2/kWh battery
Nature Energy	2024	Global	Recycling reduces 25%
TERI	2023	India	15–25% lower EV emissions
IIT Bombay	2024	India	45% reduction with renewables
Bieker	2021	Europe	Break-even 30k–60k km
IEEE TTE	2025	Asia	Grid dependency dominant

III. LIFE CYCLE ASSESSMENT FRAMEWORK

A. ISO 14040 Methodology

The research will be based on ISO 14040 LCA and include:

I. Goal and scope definition

II. “Life cycle inventory (LCI)”

III. “Life cycle impact assessment (LCIA)”

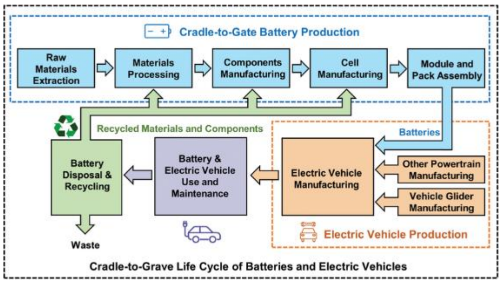
IV. Interpretation

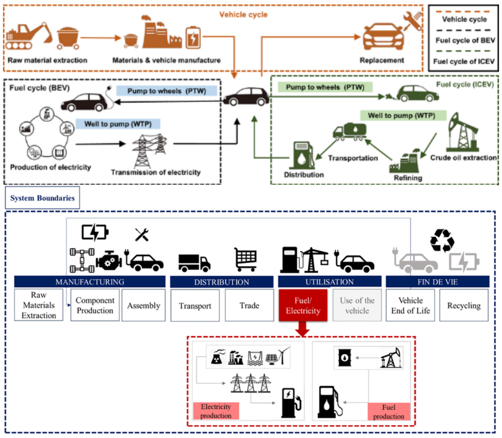
The functional unit considered is 150,000km vehicle lifetime.

B. System Boundary

The cradle-to-grave boundary includes:

- Raw material extraction
- Component manufacturing
- Vehicle assembly
- Use phase
- Maintenance
- End-of-life recycling





IV. ENERGY CONVERSION THEORY

A. Internal Combustion Engine Vehicles

ICEVs operate through combustion-based thermodynamic cycles such as Otto and Diesel cycles. Thermal efficiency is expressed as:

$$\eta_{ICE} = \frac{W_{out}}{Q_{in}}$$

Typical efficiency ranges from 20–30% [4].

Major energy losses occur due to:

Exhaust heat
Friction
Cooling system losses

B. Electric Vehicles

EVs utilize electric motors with efficiency expressed as:

$$\eta_{EV} = \frac{P_{mechanical}}{P_{electrical}}$$

Motor efficiency typically exceeds 85–95% [5].

However, upstream emissions arise from electricity generation and battery production.

V. MATHEMATICAL EMISSION MODEL

Total life cycle emissions:

$$E_{total} = E_{manufacturing} + E_{use} + E_{maintenance} + E_{EOL}$$

A. Manufacturing Emissions

Battery emission model:

$$E_{battery} = C_{battery} \times EF_{battery}$$

For a 40-kWh battery:

$$E_{battery} = 40 \times 100 = 4000 \text{ kg } CO_2$$

Manufacturing emissions are summarized in Table I.

TABLE I: MANUFACTURING EMISSIONS COMPARISON

Component	EV (t CO_2)	ICE (t CO_2)
Chassis	5	5
Powertrain	2	3
Battery	4	0
Assembly	1	0
Total	12	8

B. Operational Emissions

1) EV Operational Emissions

$$E_{EV-use} = EC \times GEF \times D$$

Where:

EC = 0.15 kWh/km
GEF = 0.7 kg CO_2/kWh
D = 150,000 km

$$E_{EV-use} = 15.75 \text{ t } CO_2$$

2) ICE Operational Emissions

$$E_{ICE-use} = FC \times EF \times D$$

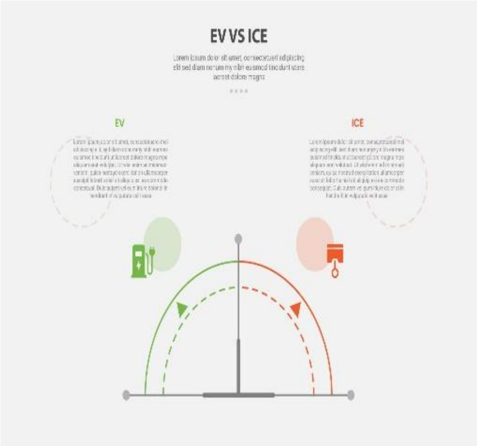
FC = 0.06 L/km
EF = 2.31 kg CO_2/L

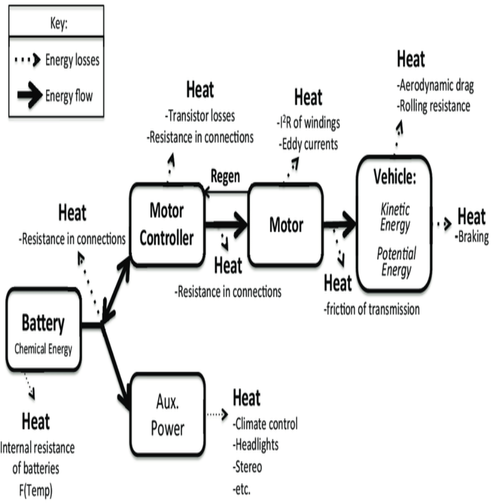
$$E_{ICE-use} = 20.79 \text{ t } CO_2$$

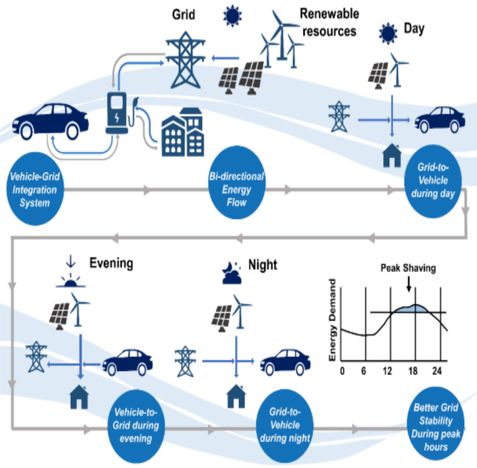
TABLE II: TOTAL LIFE CYCLE EMISSIONS

Stage	**EV (t CO_2)**	**ICE (t CO_2)**
Manufacturing	12	8
Use Phase	15.75	20.79
Maintenance	1.2	2
End-of-Life	0.5	0.7
Total	**29.45**	**31.49**

VI. WELL-TO-WHEEL ANALYSIS







Well-to-Wheel analysis includes:

1. Well-to-Tank (fuel production or electricity generation)
2. Tank-to-Wheel (vehicle operation)

EV emissions are shifted upstream, whereas ICEVs emit directly during operation.

VII. SENSITIVITY ANALYSIS

A. Renewable-Rich Grid Scenario (0.4 kg/kWh)

$$E_{EV-use} = 9 \text{ t } CO_2$$

Total EV emissions reduce to 22.7 t CO_2.

B. Coal-Dominant Grid Scenario (0.9 kg/kWh)

$$E_{EV-use} = 20.25 \text{ t } CO_2$$

Total EV emissions increase to 33.95 t CO_2.

VIII. BREAK-EVEN ANALYSIS

Manufacturing difference:

4 t CO_2

Operational saving per km:

$$0.1386 - 0.105 = 0.0336 \text{ kg/km}$$

Break-even distance:

$$\frac{4000}{0.0336} = 119{,}047 \text{ km}$$

EV becomes environmentally superior after approximately 120,000 km.

IX. DISCUSSION

1. EV manufacturing emissions are significantly influenced by battery production.
2. Operational emissions dominate the ICE vehicle life cycle impact.
3. Grid carbon intensity is the most critical parameter.
4. Battery recycling can reduce embodied emissions by 20–30% [6].

X. CONCLUSION

This post-2020 cradle-to-grave life cycle assessment shows that EVs have a lower lifetime carbon footprint than ICEVs at present Indian grid conditions. Despite EV manufacturing emissions being greater, the operational efficiency is compensated for during the lifetime of the vehicle. The major change agents to enhance sustainability performance are grid decarbonization and battery recycling.

REFERENCES

[1] International Energy Agency, *Global EV Outlook 2023*. Paris, France: IEA Publications, 2023.

[2] International Council on Clean Transportation (ICCT), *Lifecycle emissions of electric vehicles*. Washington, DC, USA, 2022. [Online]. Available: https://theicct.org/

[3] International Organization for Standardization, *ISO 14040:2006—Environmental management: Life cycle assessment—Principles and framework*. Geneva, Switzerland, 2006.

[4] J. B. Heywood, *Internal Combustion Engine Fundamentals*, 2nd ed. New York, NY, USA: McGraw-Hill, 2018.

[5] IEEE Transactions on Transportation Electrification, vol. 10, no. 1, 2024.

[6] Nature Energy, “Battery recycling and carbon footprint reduction,” 2024.

[7] F. Farzaneh, “Lifecycle carbon footprint comparison between internal combustion engine versus electric transit vehicle: A case study in the U.S.,” *Journal of Cleaner Production*, vol. 390, Art. no. 136111, Mar. 2023, doi: 10.1016/j.jclepro.2023.136111.

[8] International Council on Clean Transportation (ICCT), *A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars*, Working Paper, Jul. 2021. [Online]. Available: https://theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars/

[9] International Council on Clean Transportation (ICCT), *Life-cycle greenhouse gas emissions of passenger cars and two-wheelers in India*, Fact Sheet, Dec. 2021. [Online]. Available: https://theicct.org/wp-content/uploads/2021/12/lca-ghg-emissions-ice-evs-india-sept21_0.pdf

[10] A. Yadav *et al.*, *Life-cycle greenhouse gas emissions of battery electric heavy-duty vehicles produced in India*. International Council on Clean Transportation, May 2024. [Online]. Available: https://theicct.org/wp-content/uploads/2024/05/ID-86-LCA-HDVs-India_final3.pdf

[11] P. K. Das, M. Y. Bhat, and S. Sajith, “Life cycle assessment of electric vehicles: A systematic review of literature,” *Environmental Science and Pollution Research*, 2023, doi: 10.1007/s11356-023-30999-3.

[12] International Energy Agency, *EV life cycle assessment calculator*, 2024. [Online]. Available: https://www.iea.org/data-and-statistics/data-tools/ev-life-cycle-assessment-calculator

[13] International Energy Agency, *Comparative life-cycle greenhouse gas emissions of a mid-size BEV and ICE vehicle*,

2021. [Online]. Available: https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle

[14] Nature Communications, "Battery electric vehicles show the lowest carbon footprints among passenger vehicle options across global futures," *Nature Communications*, 2025. [Online]. Available: https://www.nature.com/articles/s43247-025-02447-2

[15] V. Vieira *et al.*, "Comparison of battery electric vehicles and internal combustion engine vehicles based on life cycle assessment," *Applied Sciences*, vol. 15, no. 6, 2025. [Online]. Available: https://www.mdpi.com/2076-3417/15/6/3122

[16] "Life cycle assessment of greenhouse gas emissions of electric and internal combustion engine vehicles in India," *Journal of Industrial Ecology*, 2022. [Online]. Available: https://www.researchgate.net/publication/362251690_Life_Cycle_Assessment_of_Greenhouse_Gas_Emissions_of_Electric_and_Internal_Combustion_Engine_Vehicles_in_India