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Electric Vehicles in India: Do They Truly Achieve Sustainability? Evidence From Lifecycle and Cost Analysis

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***Abstract*— the growing urgency to decarbonize the transportation sector has accelerated the adoption of Battery Electric Vehicles (BEVs) in India. However, their environmental and economic viability remains contingent upon lifecycle emissions and contextual factors such as electricity generation sources. This study conducts a comparative evaluation of BEVs and petrol Internal Combustion Engine (ICE) vehicles using an integrated Life Cycle Assessment (LCA) and Total Cost of Ownership (TCO) approach over a vehicle lifetime of 200,000 km. The results indicate that BEVs reduce lifecycle greenhouse gas emissions by approximately 32-45% relative to ICE vehicles. From an economic perspective, BEVs achieve near cost parity due to lower operating and maintenance costs, despite higher initial investment. The study concludes that while BEVs offer substantial sustainability benefits, their effectiveness is strongly dependent on grid decarbonisation and technological advancements (ICCT, 2024).**

***Keywords*— Battery Electric Vehicles, Lifecycle Assessment, Total Cost of Ownership, Carbon Emissions, Sustainable Transport, India**

I. Introduction

India's transportation sector is experiencing rapid expansion, contributing significantly to greenhouse gas emissions and urban air pollution. The widespread use of petrol-based Internal Combustion Engine (ICE) vehicles has intensified environmental concerns, prompting a shift toward alternative propulsion technologies. Among these, Battery Electric Vehicles (bevs) have gained prominence due to their potential to eliminate tailpipe emissions and improve energy efficiency.

Nevertheless, the environmental superiority of bevs cannot be assessed solely on operational emissions. In the indian context, where electricity generation is predominantly fossil-fuel-based, particularly coal, upstream emissions play a critical role. Lifecycle assessment (lca) studies indicate that ice vehicles emit approximately 272 g co_2e per kilometre, while bevs exhibit emissions ranging from 150 to 185 g co_2e per kilometre depending on grid conditions. Over a standard operational lifetime of 200,000 km, this translates into emission reductions of approximately 32–45% for bevs (icct, 2024).

In addition to environmental considerations, economic feasibility remains a key determinant of adoption. Although BEVs typically involve higher upfront costs, they offer significant savings in terms of fuel and maintenance. Consequently, lifecycle cost evaluations suggest that BEVs are approaching cost parity with ICE vehicles. This study aims to provide a comprehensive assessment of both environmental and economic dimensions to better understand the role of BEVs in India's transition toward sustainable mobility.

II. Literature Review

The sustainability of Battery Electric Vehicles (BEVs) has been widely examined through lifecycle assessment (LCA) and techno-economic analyses. A key consensus in the literature is that evaluating vehicle emissions solely at the tailpipe level is insufficient; instead, a comprehensive lifecycle perspective is required, incorporating manufacturing, operation, and end-of-life stages.

Several studies confirm that BEVs generally exhibit lower lifecycle greenhouse gas (GHG) emissions compared to Internal Combustion Engine (ICE) vehicles. For instance, Hirz and Nguyen (2022) demonstrate that electric vehicles significantly reduce CO_2-equivalent emissions over their lifecycle, although the extent of reduction depends on electricity generation sources. Similarly, Shafique et al. (2022) and Oliveri et al. (2023) highlight that BEVs outperform ICE vehicles in lifecycle emissions across different geographic contexts, with reductions becoming more pronounced in regions with cleaner electricity grids.

The role of electricity generation mix is consistently identified as a critical determinant of BEV sustainability. Dulău (2023) and the International Energy Agency (IEA, 2023) emphasize that the carbon intensity of electricity directly influences lifecycle emissions, with renewable energy integration substantially enhancing environmental benefits. In the Indian context, studies by Dhar and Shukla (2015) and NITI Aayog (2025) indicate that decarbonizing the power sector is essential for maximizing the emission reduction potential of electric mobility.

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Another important aspect discussed in the literature is the higher manufacturing emissions associated with BEVs, primarily due to battery production. Research by Raugei (2022) and Rapa et al. (2020) suggests that although BEVs may have a higher initial carbon footprint, these emissions are offset during the use phase due to higher efficiency and zero tailpipe emissions. This finding is further supported by Das (2022), who reports that BEVs can achieve significant net emission reductions over their operational lifetime.

In addition to environmental performance, several studies have analyzed the economic viability of electric vehicles using Total Cost of Ownership (TCO) frameworks. Kumar and Chakrabarty (2020) demonstrate that BEVs can become economically competitive with ICE vehicles under higher usage conditions due to lower energy and maintenance costs. Similarly, Breetz and Salon (2018) highlight that while BEVs have higher upfront costs, long-term savings can offset initial investments. Techno-economic analyses by Das et al. (2020), Pg Abas et al. (2019), and Yusuf et al. (2023) further confirm that declining battery costs and improved efficiency enhance the financial attractiveness of BEVs.

Moreover, studies such as Falcão et al. (2017) and BloombergNEF (2024) emphasize that battery cost reduction is a key driver of EV adoption, while policy support plays a crucial role in overcoming initial cost barriers. The International Council on Clean Transportation (ICCT, 2024) also provides evidence that BEVs consistently achieve lower lifecycle emissions than ICE vehicles, reinforcing their potential as a sustainable transport solution.

Despite these advantages, the literature acknowledges several challenges, including dependence on fossil-fuel-based electricity, high initial investment costs, and uncertainties related to battery lifecycle management. These factors underscore the importance of integrated policy approaches that simultaneously address energy decarbonisation and transportation electrification.

In summary, existing research establishes that BEVs offer significant environmental and economic benefits compared to ICE vehicles. However, the magnitude of these benefits is highly context-dependent, necessitating region-specific analyses such as the present study to accurately assess their sustainability in the Indian context. Evaluation of electric vehicle sustainability has increasingly relied on lifecycle-based methodologies. Previous studies emphasize that assessing only tailpipe emissions leads to incomplete conclusions, as upstream processes such as electricity generation and battery manufacturing significantly influence overall emissions.

Research by the International Council on Clean Transportation (ICCT) demonstrates that BEVs generally exhibit lower lifecycle emissions compared to ICE vehicles, even in regions with carbon-intensive electricity grids (ICCT, 2024). Similarly, the International Energy Agency highlights that the environmental performance of BEVs improves substantially with increasing penetration of renewable energy sources (IEA, 2023).

A recurring theme in the literature is the higher manufacturing emissions associated with BEVs due to battery production. Studies by Raugei (2022) and Rapa et al. (2020) indicate that while BEVs may initially have a larger carbon footprint, these emissions are offset during the use phase due to higher energy efficiency and absence of combustion-related emissions. In the Indian context, Das (2022) reports that BEVs can achieve lifecycle emission reductions of approximately 40% compared to conventional vehicles.

Economic analysis further support the case for BEVs. Declining battery costs along with lower operating expenses have been acknowledged as key factors driving cost competitiveness of BEVs (BloombergNEF, 2024). Policy frameworks, together with subsidies and infrastructure development, also play a vital role in facilitating adoption of electric vehicles (NITI Aayog, 2025).

Despite these advantages, the literature concedes several challenges, including dependence on fossil fuel based electricity, high initial costs, and worries related to battery lifecycle management. These findings highlight the importance of context specific analysis, mainly in emerging economies like India.

III. Research Objectives

The study aims to:

- Compare lifecycle greenhouse gas emissions of BEVs and ICE vehicles
- Evaluate Total Cost of Ownership over a representative vehicle lifetime
- Provide insights to support sustainable mobility policy development

IV. Methodology

A. Data Collection

The study is based on a comprehensive review and synthesis of secondary data gained from authentic reports published by various agencies, Government reports and published literatures and sources.

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Lifecycle emissions data are derived from International Council on Clean Transportation (ICCT) India reports, while vehicle pricing, fuel costs, and electricity tariffs are obtained from credible Indian market databases and manufacturer disclosures (Tata motors). Battery cost trends are referenced from Bloomberg NEF, and policy-related data are sourced from Government of India publications.

B. *Analytical Framework*

The research adopts an integrated analytical framework combining:

Life Cycle Assessment (LCA): A cradle-to-grave approach encompassing vehicle manufacturing, battery production, fuel/electricity generation, use-phase emissions, and end of life considerations.

Total Cost of Ownership (TCO) Analysis: A lifecycle cost evaluation including vehicle purchase price, fuel/electricity expenditure, maintenance costs, and battery replacement where applicable.

This dual-framework approach enables a holistic comparison of environmental and economic performance.

C. *Key Assumptions*

The analysis is conducted under a standardized baseline scenario with the following assumptions:

Vehicle lifetime: 200,000 km

ICE emissions intensity: 272 g CO_2e/km

ICE Mileage: 17 km/liter

Petrol price: ₹95 per litre

BEV emissions range: 150–185 g CO_2e/km

Electricity tariff: ₹8 per kWh

BEV energy consumption: 0.15 kWh/km

Battery replacement cost: ₹3.8 lakh

These assumptions reflect realistic operating conditions in the Indian context.

V. LIFE-CYCLE EMISSIONS ANALYSIS

In this section we will compare BEVs and ICEs based on their Co2 Emission over the period of their entire life cycle, which is assumed to be 200,000 Kilometres.

TABLE I
LCA EMISSIONS

Powertrain	Emissions (g CO_2e/km)
ICE	272
BEV (Low)	150
BEV (High)	185

TABLE II
LIFETIME EMISSIONS

Vehicle	Calculation	Emissions (tCO_2e)
ICE	$(272 \times 200{,}000) \div 10^6$	54.4
BEV Low	$(150 \times 200{,}000) \div 10^6$	30.0
BEV High	$(185 \times 200{,}000) \div 10^6$	37.0

TABLE III
COMPARATIVE ANALYSIS

Vehicle	Emissions	Reduction	% Reduction
ICE	54.4	—	—
BEV Low	30.0	24.4	44.9%
BEV High	37.0	17.4	32.0%

The life time emission is calculated based on (**g CO_2e/km* Vehicle lifetime/10^6**) the results confirm that BEVs provide substantial reductions in lifecycle emissions, even under current grid conditions (ICCT, 2024).

VI. TOTAL COST OF OWNERSHIP ANALYSIS

In this part we will compute the total cost of owning BEVs and ICEs and then comparative analysis of total cost of ownership will be conducted hereunder.

A. *ICE Vehicle*

Purchase price: ₹7.31 lakh

Fuel cost = Fuel consumption*fuel cost

$$11{,}764 \times 95 = ₹11.19 \text{ lakh}$$

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Fuel consumption = Vehicle Lifetime*Mileage

200,000 / 17 = 11,764 L

Maintenance total (10 years) = ₹1.20 lakh.

ICE total lifetime cost = 7.31 + 11.19 + 1.20 = **₹19.70 lakh**

B. BEV (Battery electric vehicle)

Purchase price: ₹12.49 lakh (as per tat motors https://cars.tatamotors.com/nexon/ice/price.html)

Electricity cost = 30,000 × ₹8 = ₹2.40 lakh.

Electricity consumption = 0.15 kWh/km×200,000 = 30,000 kWh

Maintenance total = ₹0.50 lakh.

Battery replacement cost (once) = ₹3.80 lakh.

BEV total lifetime cost (baseline) = 12.49 + 2.40 + 0.50 + 3.80 = **₹19.19 lakh.**

TABLE IV
TCO COMPARISON

Component	ICE	BEV
Purchase	7.31	12.49
Energy	11.19	2.40
Maintenance	1.20	0.50
Battery	0	3.80
Total	**19.70**	**19.19**
TCO Difference	(ICE-BEV)	−₹0.51 lakh

Purchase price is taken from the official website of Tata motors (https://cars.tatamotors.com/nexon/ice/price.html)

BEVs demonstrate marginal cost savings of ₹0.51 lakh over their lifecycle due to lower operating expenses (BloombergNEF, 2024). Therefore based on the assumptions taken to conduct the study, BEV has lower total cost of ownership over OEC vehicles in India.

VII. Limitations

Despite its comprehensive approach, the study is subject to certain limitations:

- The analysis is based on a representative vehicle model, and results may vary across different vehicle categories and specifications.
- Resale value, depreciation, and financing costs are not incorporated into the TCO analysis, potentially affecting real-world economic outcomes.
- Variations in regional electricity tariffs and charging infrastructure availability are not explicitly modeled.
- The study does not quantify local air pollution and health co-benefits, which are important externalities associated with reduced ICE vehicle usage.
- Assumptions related to lifecycle parameters and operational conditions may introduce uncertainty in results.

VIII. Policy Implications

The findings of this study provide several important insights for policymakers and stakeholders:

A. Decarbonisation of the Electricity Grid:

Enhancing the share of renewable energy in India's electricity mix is essential to maximize the environmental benefits of BEVs.

B. Promotion of Efficient Charging Infrastructure:

Encouraging residential charging, time-of-use tariffs, and integration with rooftop solar systems can reduce both emissions and operating costs.

C. Support for Battery Ecosystem Development:

Investments in domestic battery manufacturing, recycling, and second-life applications can reduce lifecycle emissions and improve resource efficiency.

D. Targeted Electrification Strategies:

Prioritizing high-utilization vehicle segments such as taxis, ride-hailing services, and public transport can yield faster environmental and economic returns.

E. Financial and Regulatory Incentives:

Innovative financing mechanisms and policy support can help mitigate high upfront costs and accelerate EV adoption.

IX. Conclusion

This study presents a comprehensive evaluation of the environmental and economic performance of Battery Electric Vehicles in comparison to conventional petrol ICE vehicles in India. The results demonstrate that BEVs achieve significant lifecycle emission reductions, in the range of 32-45%, even under current grid conditions.

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From an economic perspective, BEVs exhibit near cost parity with ICE vehicles over a typical lifetime, with lower operational and maintenance costs offsetting higher initial investments.

However, the extent of these benefits is strongly influenced by factors such as electricity grid composition, battery cost trajectories, and usage patterns. As India continues its transition toward cleaner energy systems, the relative advantages of BEVs are expected to strengthen further.

Overall, the findings underscore the importance of adopting an integrated policy approach that simultaneously promotes electric mobility and clean energy generation. Such a strategy is essential to achieving long-term sustainability and decarburization objectives in the transportation sector.

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