World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(Review Article)

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Comprehensive analysis of the environmental impact of Electric Vehicles (EVs)

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World Journal of Advanced Engineering Technology and Sciences, 2024, 13(02), 663-670

Publication history: Received on 10 November 2024; revised on 26 December 2024; accepted on 28 December 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.2.0656

Abstract

Electric Vehicles (EVs) have emerged as a pivotal solution in the fight against climate change, A means to lower greenhouse gas emissions and lesser reliance on fossil fuels. While celebrated for their potential environmental benefits, EVs also present challenges, particularly in battery manufacturing, resource extraction, and energy usage. This paper provides a detailed exploration of the environmental implications of EVs, analyzing their entire lifecycle, from production to disposal, and comparing them with traditional Internal Combustion Engine (ICE) vehicles. By examining energy sources, lithium-ion battery technology, and recycling practices, this study evaluates whether EVs can truly deliver on their green promise. Recommendations for policy and technological innovation are proposed to maximize their sustainability.

Keywords: Electric Vehicles; Internal combustion engines; EV’s vs ICE; Environmental impacts of Ev’s and ICE

1. Introduction

The shift to Electric Vehicles (EVs) has been driven by the urgent need to mitigate climate change and address the ecological effects of traditional vehicles. Proponents highlight their efficiency, zero tailpipe emissions, and potential to reduce air pollution in urban areas. However, critical questions remain about the sustainability of EVs, particularly regarding their reliance on lithium-ion batteries and the electricity grids that power them. This paper aims to explore these issues comprehensively, presenting a balanced view of the environmental impact of EVs and identifying areas for improvement.

2. What Are Electric Vehicles (EVs)?

EVs are automobiles that operate using electricity stored in batteries or alternative energy storage devices. They are divided into three primary categories:

- **Battery Electric Vehicles (BEVs):** Fully electric vehicles powered by rechargeable batteries, producing zero tailpipe emissions.
- **Plug-in Hybrid Electric Vehicles (PHEVs):** Combine electric motors and internal combustion engines, allowing operation in both electric and fuel modes.
- **Hybrid Electric Vehicles (HEVs):** Use an electric motor to assist the internal combustion engine, improving fuel efficiency without external charging.

Electric vehicles provide benefits like decreased greenhouse gas emissions, quieter performance, and reduced operational expenses. However, their environmental footprint depends on the electricity mix, battery production processes, and end-of-life management.

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3. Environmental Impact of EVs

3.1. Production Phase

The production of lithium-ion batteries marks the starting point of the environmental impact associated with electric vehicles. These batteries rely on materials like lithium, cobalt, nickel, and manganese, which are extracted through mining processes that can disrupt ecosystems and local communities. For example:[5] [7]

- **Lithium Mining:** Often conducted in water-scarce regions, it consumes large quantities of water and may lead to groundwater depletion.[4]
- **Cobalt Mining:** Concentrated in countries like the Democratic Republic of Congo, cobalt mining raises concerns about unethical labour practices and environmental degradation.

3.2. Energy Sources for Charging

The environmental benefits of EVs are closely tied to the electricity sources used for charging. In countries with coal-dominated grids, EVs may produce significant indirect emissions. However, as renewable energy penetration increases, the net emissions from EVs decrease substantially.

3.3. Lifecycle Emissions

Lifecycle assessments consider emissions from production, operation, and disposal. Studies indicate that while EVs have higher production emissions compared to ICE vehicles, their operational phase offsets this difference. For example, a typical EV produces around 4,587 pounds of CO_2 annually, compared to 23,885 pounds for a conventional gasoline vehicle.[7]

3.4. End-of-Life Management

Managing the recycling and disposal of EV batteries presents considerable difficulties. Existing recycling methods are not widely adopted, leading to concerns about waste and resource depletion. Effective recycling systems are crucial for reclaiming valuable resources and reducing ecological damage.

4. Comparative Analysis: EVs vs. ICE Vehicles [7]

The comparison between EVs and ICE vehicles involves multiple dimensions:

- **Emissions:** EVs significantly reduce tailpipe emissions. In regions with clean energy grids, the total lifecycle emissions of EVs are far lower than those of ICE vehicles.[6]
- **Energy Efficiency:** EVs convert over 60% of the electrical energy to the wheels, compared to about 20% for ICE vehicles.[1]
- **Cost:** While EVs have higher initial costs, they benefit from lower fuel and maintenance expenses.
- **Performance:** EVs offer instant torque and smoother acceleration, enhancing driving experience.

4.1. Graphical Comparison

Below are visual representations of key comparisons:

Table 1 Cars used for comparison

Sr. No	Battery electrical vehicles	Internal combustion engine
1	Tata Nexon	Tata Nexon
2	Hyundai Kona Electric	Hyundai Creta SX
3	MG ZS EV	MG Hector
4	Mahindra XUV 400	Mahindra XUV

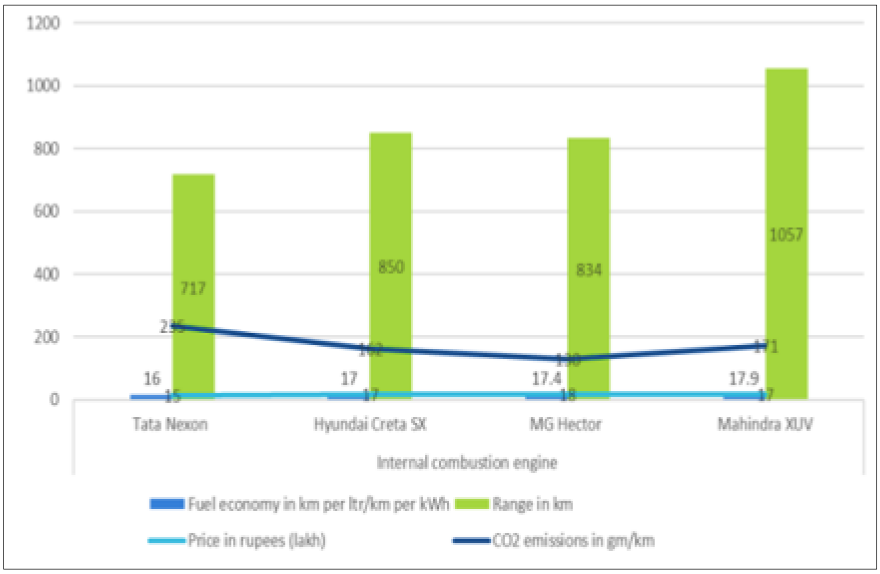

Figure 1 Based on Internal Combustion Engine

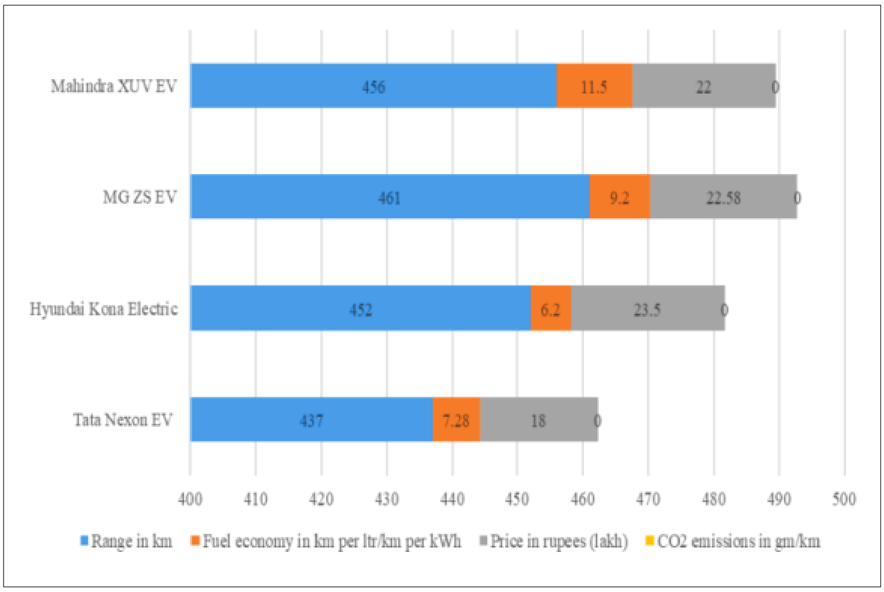

Figure 2 Battery electrical vehicles (EV’s)

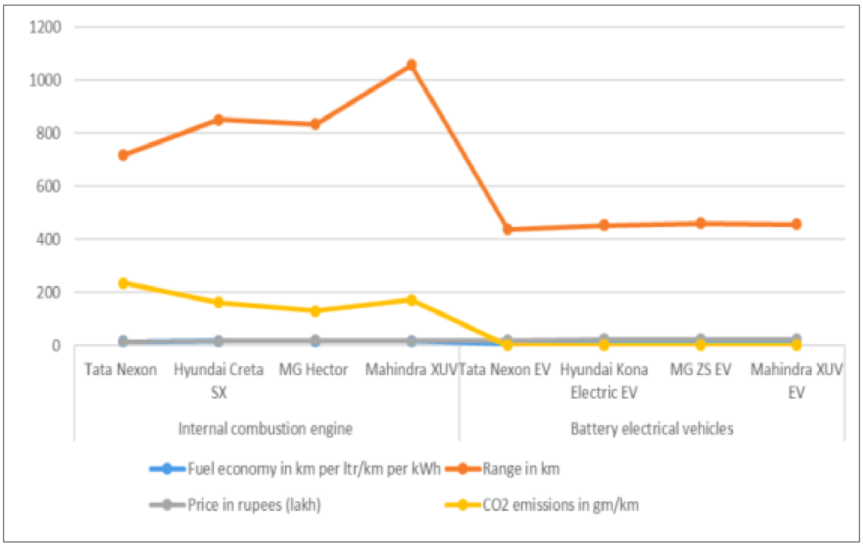

Figure 3 Comparison of IC Engine and Battery based vehicles

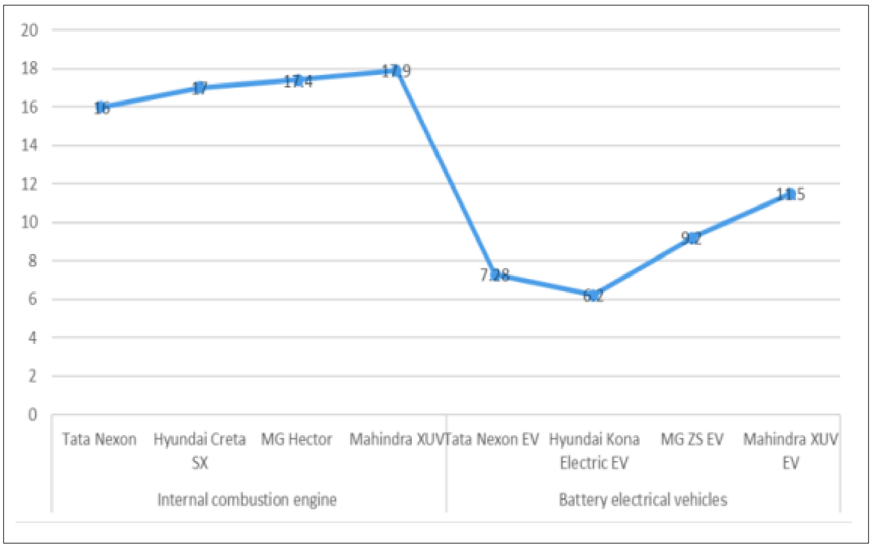

Figure 4 Fuel Economy in km/litre per kWh

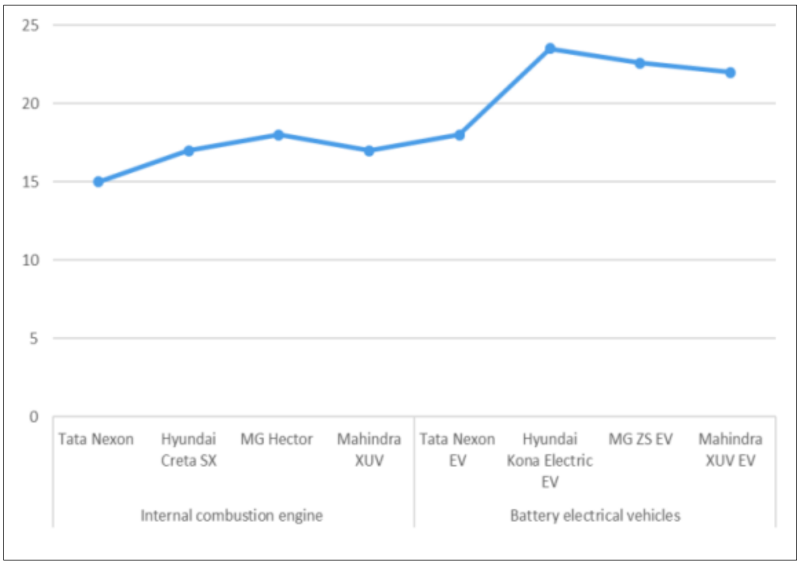

Figure 5 Price in rupees (lakh)

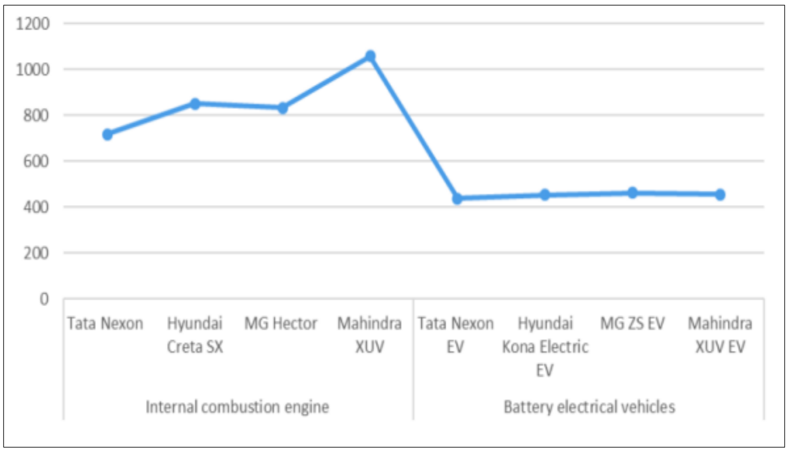

Figure 6 Range in km

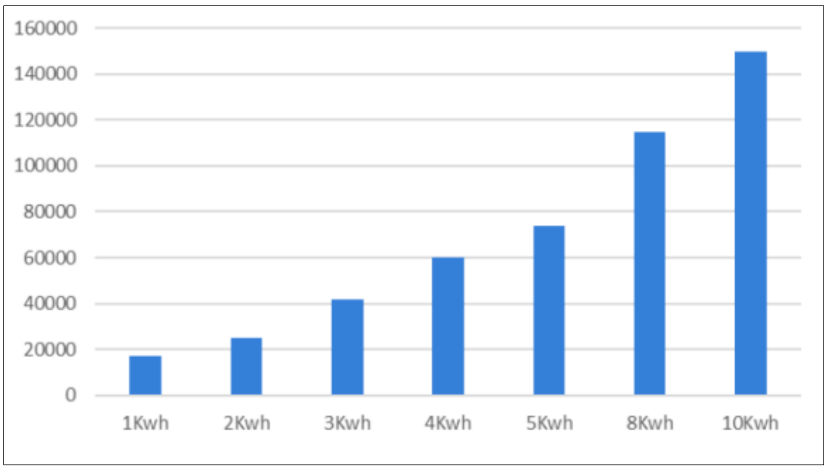

Figure 7 Price in India (Simple BMS)

5. Lithium-Ion Batteries: Technology and Challenges

Lithium-ion batteries are central to EV technology. Key features include:

- **Energy Density:** Modern lithium-ion batteries provide higher energy density, enabling longer driving ranges.
- **Cost Trends:** The cost of lithium-ion batteries has decreased significantly, from $900 per kilowatt-hour in 2008 to around $300 today.[5]
- **Material Constraints:** Limited availability of high-quality lithium and cobalt poses challenges for scaling up production.

Efforts to develop alternative chemistries, such as solid-state batteries, are underway to address these issues.

6. Environmental Challenges of Lithium Mining [4]

Lithium mining, particularly in regions like the "Lithium Triangle" (Argentina, Bolivia, and Chile), presents several challenges:[4]

- **Water Scarcity:** Extraction processes consume vast amounts of water, affecting local ecosystems and communities.
- **Chemical Pollution:** Toxic chemicals used in extraction can contaminate soil and water sources.[4]
- **Social Impacts:** Mining operations often disrupt local livelihoods and indigenous cultures.

7. Elements Required for Lithium-Ion Batteries

The key components of lithium-ion batteries include:

- **Lithium:** Critical for energy storage; primarily sourced from brine and hard rock mining.
- **Cobalt:** Used in the cathode for stability and energy density but associated with ethical concerns.
- **Nickel:** Enhances energy density; used in nickel-cobalt-aluminium (NCA) and nickel-cobalt-manganese (NCM) chemistries.
- **Graphite:** Essential for the anode; stores lithium ions during charging and releases them during discharging.
- **Manganese:** Improves thermal stability and safety; used in certain cathode chemistries like lithium manganese oxide (LMO).

8. Methodology

This study reviews scholarly articles and government reports from databases such as ScienceDirect, the United States Department of Energy, and the Environmental Protection Agency. Keywords like "environmental impact of EVs," "lithium-ion battery recycling," and "renewable energy for EVs" were used to gather relevant information.

9. Lithium extraction and processing can lead to substantial environmental consequences

- The expanding global demand for efficient electric batteries and other lithium-based products has brought serious concerns about the potential environmental impacts of lithium mining, which encompasses both lithium extraction and processing.[3] [9]
- The environmental concerns are especially related to air, water and soil pollution, as well as the depletion of water resources upon which many local communities in these lithium mining regions are dependent.[3]
- In addition to the toxic chemicals used during lithium processing, trace amounts of lithium can also be found in waste storage ponds, tailings piles, processed waters, evaporation basins and transported materials can lead to biophysical effects, potentially harming human metabolism, nerve function, soil health, and aquatic ecosystems. Further, evaporation ponds are typically lined with polyvinyl chloride (PVC) as a protective barrier, which could potentially fail, leading to the introduction of contaminants into the environment.[3]
- The concerns are especially alarming given that environmental impact evaluation tools, such as life-cycle assessment, prevalent in other engineering disciplines are significantly limited in mining due to a lack of adequately defined quantifiable impact categories (e.g. water toxicity, eutrophication) and functional units. Functional units are those elements used to quantify productivity in many life-cycle assessment studies. For example, brine evaporitic technology can have adverse impacts on water usage, flora and fauna, waste

generation and disposal, and land subsidence, but there are very few studies linking the quantity of lithium produced to the extent of these forms of environmental impact.[5]

- Some estimates tag water consumption by evaporative technology at approximately 500,000 gallons per ton of lithium extracted. Reports indicate that nearly 95% of the extracted brine water is permanently lost due to evaporation. In Australia, 98 per cent of the 3,300 tons of the waste is not recycled. The Chilean government's Committee of Non-Metallic Mining reports that water extraction from Salar de Atacama rose by 21% between 2000 and 2015. As a result, the local groundwater levels in the region have been depleted by as much as 1 meter per year in some areas. In arid places (i.e. places with 100–200 mm/year average precipitation), such as the lithium triangle, groundwater is critical for human consumption, livestock, crop irrigation and native plant species, and thus the risk of contamination is a legitimate concern.[2]

10. Results and discussion

10.1. Key Findings

- **Emission Reductions:** EVs can reduce greenhouse gas emissions by up to 50% compared to ICE vehicles, depending on the electricity mix.[1]
- **Infrastructure Challenges:** Expansion of charging networks and recycling facilities is critical for supporting widespread EV adoption.
- **Policy Implications:** Governments play a vital role in incentivizing renewable energy adoption and sustainable mining practices.

10.2. Opportunities for Improvement

- Enhancing the integration of renewable energy sources into power grids.
- Developing advanced recycling technologies for batteries.
- Encouraging innovation in battery chemistries to reduce dependency on scarce materials.

11. Conclusion

Electric Vehicles offer a promising pathway to achieving global emission reduction targets. However, their environmental impact is not negligible, especially in terms of resource extraction and energy dependency. A concerted effort is required from governments, industries, and researchers to address these challenges. By improving energy infrastructure, refining battery technology, and establishing robust recycling frameworks, EVs can truly fulfil their potential as a green transportation solution.

Compliance with ethical standards

Acknowledgement

The author acknowledges that this research was conducted independently and received no specific funding or external support.

Disclosure of conflict of interest

The author declares that they have no conflict of interest.

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