

# Electric Mobility Expansion and the Reconfiguration of Environmental Resource Pressures

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**Abstract:** This study examines the environmental implications of the rapid evolution and adoption of Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs), focusing on their alignment with Sustainable Development Goals (SDGs). The primary objective is to critically evaluate whether the large-scale transition to EVs genuinely mitigates environmental degradation or shifts ecological burdens across sectors and regions. The methodology involves a qualitative and data-driven review of battery production impacts, raw material extraction (lithium, cobalt, nickel), charging infrastructure expansion, fossil-fuel-based electricity dependence, and lifecycle ecological footprint indicators presented in the source document. Comparative observations are also drawn between emission reductions during COVID-19 quarantine periods and projected EV-driven reductions under fossil-dominated grids. The novelty of this study lies in integrating ecological footprint metrics (global hectares), SDG-linked damage assessment (SDGs 6, 7, 12, 13, and 15), geopolitical material dependency analysis, and infrastructure cost evaluation into a single sustainability framework, rather than limiting discussion to tailpipe emission reductions. Findings indicate that although EVs reduce urban exhaust emissions and support long-term decarbonization goals, significant upstream impacts persist, including water depletion from lithium extraction, soil and groundwater contamination from cobalt mining, habitat destruction, grid stress, and high carbon intensity in battery manufacturing. Battery recycling challenges and fossil-based grid electricity further limit net climate benefits. However, integration of renewable energy sources such as solar photovoltaic systems can reduce the ecological footprint of charging infrastructure by nearly 90%, substantially improving sustainability outcomes. The study concludes that EV expansion without responsible mining practices, circular economy systems, and clean energy integration risks externalizing environmental damage, thereby undermining progress toward multiple SDGs despite apparent reductions in transportation.

**Keywords:** *Electric Vehicle, Hybrid Electric Vehicle, Electric Vehicle Powertrain, Energy Storage Systems, Vehicle Dynamics.*

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## I. INTRODUCTION

The rapid transition toward electric mobility has emerged as one of the most significant technological and environmental shifts of the twenty-first century. Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) are widely promoted as cleaner alternatives to conventional Internal Combustion Engine (ICE) vehicles, primarily because they eliminate tailpipe emissions and reduce urban air pollution[1]. However, the broader environmental narrative surrounding EV adoption is complex and deeply interconnected with resource extraction, energy systems, industrial manufacturing, and global sustainability goals. The evolution of EVs has been driven by climate change concerns, rising fossil fuel prices, urban pollution crises, and

international climate agreements[2]. Over the past decade and a half, battery capacities have improved, vehicle ranges have expanded, and battery costs have significantly declined, enabling mass adoption across major markets such as China, the United States, and Europe. Governments, including India, have allocated large financial budgets and policy incentives to accelerate EV infrastructure development and charging networks[3]. Despite these advancements, the environmental footprint of EV production and deployment demands critical examination. While EVs reduce operational emissions, their lifecycle impacts from mining to disposal raise questions about sustainability[4]. Therefore, understanding the background of EV evolution requires balancing technological optimism with ecological accountability, ensuring that the transition to

electric mobility does not unintentionally create new environmental pressures while attempting to solve existing ones[5].

One of the most significant environmental concerns associated with EV expansion lies in battery production. Lithium-ion batteries, including chemistries such as  $\text{LiFePO}_4$  and lithium nickel cobalt manganese oxide, form the core of modern EV technology[6]. Extracting raw materials like lithium, cobalt, and nickel requires intensive mining operations that often occur in ecologically fragile or water-scarce regions. Lithium extraction consumes large quantities of water, contributing to groundwater depletion and salinity imbalance, particularly in arid zones. Cobalt mining has been linked to unsafe working conditions and environmental contamination, while nickel and rare earth extraction contribute to deforestation, toxic wastewater generation, and air pollution. These processes generate significant carbon emissions even before a vehicle reaches the road, and in some cases, battery production can emit more  $\text{CO}_2$  than the manufacturing of traditional ICE vehicles[7]. This shifts part of the environmental burden upstream into mining regions, often located in developing countries. As EV adoption accelerates, demand for these critical minerals increases, intensifying geopolitical dependencies and supply chain risks[8]. Thus, while EVs aim to decarbonize transportation, their production phase reveals a hidden environmental cost that challenges the perception of electric mobility as entirely “green.” A sustainable transition requires responsible sourcing, improved mining regulations, and investment in battery recycling technologies to reduce primary material extraction[9].

Beyond production, battery disposal and recycling represent another critical environmental challenge. Lithium-ion batteries are technically recyclable, but the process remains expensive, energy-intensive, and technologically complex. Improper disposal can release toxic chemicals and heavy metals into soil and groundwater systems, posing long-term ecological and public health risks[10]. As EV adoption rises, the volume of end-of-life batteries will grow exponentially over the next decade, potentially creating a future waste crisis if circular economy mechanisms are not strengthened. Current recycling rates remain limited compared to projected battery waste volumes, highlighting the urgency for improved infrastructure and regulatory frameworks[11]. Simultaneously, the source of electricity used to charge EVs significantly influences their overall environmental impact. In regions where power generation relies heavily on coal or other fossil fuels, EVs merely shift emissions from vehicle exhaust pipes to thermal power plants[12]. This indirect emission transfer reduces urban air pollution but does not fully eliminate greenhouse gas contributions. Grid stress also increases with mass charging demand, requiring upgrades in transformers, distribution lines, and charging infrastructure investments. Therefore, the environmental benefits of EVs are highly dependent on parallel renewable energy integration and smart grid development. Without decarbonizing electricity generation,

the climate advantages of EV expansion remain only partially realized[13].

The infrastructure required to support EV growth further contributes to ecological and economic considerations. The rapid expansion of public charging stations, rising from thousands to tens of thousands within a short period, reflects accelerating policy support and consumer adoption[14]. However, establishing charging stations demands significant capital investment in equipment, grid connectivity, civil works, and software systems. Each station carries an ecological footprint, and large-scale deployment increases material consumption and land use. When powered by fossil-fuel-based grids, charging infrastructure indirectly sustains emissions from coal-fired plants[15]. At the same time, EVs remain relatively expensive compared to conventional vehicles due to high battery costs, insurance premiums, and replacement expenses. Economic accessibility therefore becomes intertwined with sustainability debates. Furthermore, the shift toward electric mobility affects employment patterns, potentially reducing demand in engine manufacturing, transmission systems, and oil industries. While new jobs emerge in battery production and renewable energy sectors, the transition requires workforce reskilling and economic adaptation. These interconnected industrial, infrastructural, and social transformations highlight that EV evolution is not merely a technological upgrade but a systemic restructuring of the transportation and energy ecosystem[16].

From a global sustainability perspective, EV expansion intersects directly with multiple Sustainable Development Goals (SDGs). Unsustainable raw material extraction challenges SDG 12 (Responsible Consumption and Production) and SDG 15 (Life on Land) due to soil contamination, biodiversity loss, and habitat destruction. Water-intensive lithium extraction affects SDG 6 (Clean Water and Sanitation) through groundwater depletion and salinity changes. Additionally, if electricity grids remain fossil-dependent, the climate benefits associated with SDG 13 (Climate Action) and SDG 7 (Affordable and Clean Energy) are weakened. The COVID-19 quarantine period demonstrated that emissions could drop significantly due to reduced industrial and transportation activity, offering a natural experiment in environmental restoration[17]. Unlike lockdown-based reductions, the EV transition aims to lower emissions while sustaining economic growth. However, the comparison reveals a critical lesson: emission reduction alone is insufficient without structural energy transformation. National commitments, such as long-term renewable capacity expansion and net-zero targets, reinforce the importance of integrating clean energy with transportation electrification. Thus, EV evolution must align with broader climate strategies rather than operate as an isolated solution[18].

Therefore, the background of EV and HEV evolution reflects a dual narrative of technological progress and environmental complexity. Electric mobility offers substantial benefits in reducing urban air pollution, lowering dependence on imported fossil fuels, and advancing climate

mitigation strategies[19]. Nevertheless, battery production emissions, raw material extraction impacts, recycling limitations, grid dependency, infrastructure footprint, and geopolitical vulnerabilities reveal that EV expansion is not inherently sustainable without systemic reforms. Integrating renewable energy sources such as solar power into charging systems can significantly reduce ecological footprints and strengthen climate benefits. The transition toward hydrogen and other emerging clean technologies may further diversify long-term solutions[20]. Ultimately, a sustainable EV future depends on responsible mining, circular battery economies, renewable grid transformation, and policy coherence aligned with global climate commitments. Without these integrated measures, the shift to electric vehicles risks externalizing environmental damage rather than eliminating it. Therefore, the evolution of EVs and HEVs should be examined through a holistic lifecycle perspective that ensures environmental justice, economic resilience, and genuine progress toward sustainable development.

## II. METHODOLOGY

### ➤ *Raw Material Extraction and Ecological Degradation*

The most environmentally intensive phase of EV production lies in battery manufacturing. Lithium-ion batteries particularly chemistries such as Lithium Iron Phosphate ( $\text{LiFePO}_4$ ) and Lithium Nickel Cobalt Manganese

Oxide ( $\text{Li (NiCoMn)O}_2$ ) require the extraction of lithium, cobalt, nickel, and rare earth elements.

- Lithium mining, particularly in salt flats of arid regions, consumes massive quantities of groundwater. This extraction process can lower water tables, disrupt fragile ecosystems, and threaten agricultural communities. In water-scarce environments, such depletion intensifies environmental stress and socio-economic inequality.
- Cobalt mining, concentrated in limited regions globally, has been associated with unsafe labor practices and significant soil and groundwater contamination. Improper waste management in mining areas can lead to toxic runoff affecting biodiversity and human health.
- Nickel and rare earth mining contribute to deforestation, air pollution, and the generation of toxic wastewater. Open-pit mining operations remove large volumes of earth, permanently altering landscapes and reducing biodiversity.

Lifecycle studies indicate that battery production can generate higher initial  $\text{CO}_2$  emissions than the manufacturing of conventional ICE vehicles. While EVs compensate through lower operational emissions over time, the carbon intensity of battery manufacturing remains a significant concern.



Fig 1 Mining of Lithium, Cobalt, Nickel etc.

### ➤ *Battery Disposal and Recycling: The Emerging Waste Challenge*

The large-scale deployment of EVs implies a future wave of battery waste. Lithium-ion batteries are technically recyclable, but the process remains costly and energy-intensive. Current recycling infrastructure is insufficient to handle future volumes efficiently.

Improper disposal poses serious environmental risks. Batteries contain heavy metals and toxic electrolytes that, if released, can contaminate soil and water systems. Without robust circular economy strategies, today's climate solution could become tomorrow's hazardous waste crisis.

Establishing advanced recycling technologies, second-life battery applications, and material recovery systems is critical to preventing long-term ecological damage.

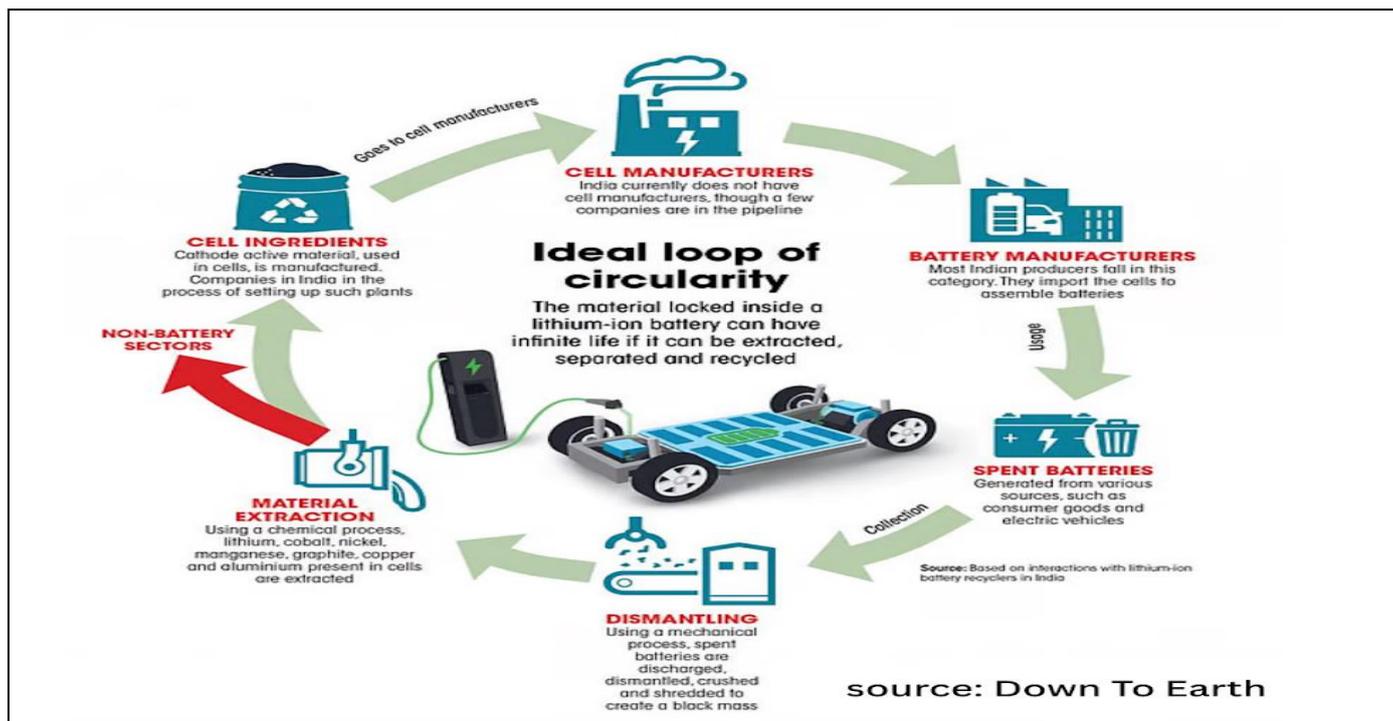


Fig 2 Recycling of Battery

➤ *Electricity Generation: Are EVs Truly Clean?*

EVs produce zero tailpipe emissions, but their true environmental benefit depends entirely on the electricity source used for charging.

In countries where coal dominates the energy mix, EV emissions are effectively transferred from urban roads to thermal power plants. This phenomenon is often described as "emission shifting." If the electricity grid remains fossil-fuel dependent, EVs offer only partial reductions in greenhouse gases.

This dynamic directly impacts global climate goals. The decarbonization of transport must be synchronized with renewable energy expansion; otherwise, the environmental advantage of EVs remains limited.

➤ *Cost of Establishing EV Charging Stations*

Table 1 Cost Estimation of One EV Charging Station

TYPE	AC EV Station (₹)	DC EV Station (₹)
Charger Equipment	50k - 1.5L	5L - 15L
Electricity & Grid	1L - 3L	5L - 10L (incl. Transformer)
Civil works	50k - 1L	1.5L - 3L
Software & Misc.	20k - 40k	50k - 1L
Total Investment	2L - 6L	15L - 25+L

Battery costs in India range between ₹15,000 and ₹60,000 per kWh. Additionally, the ecological footprint of implementing a single EV charging station is estimated at approximately 40.69 global hectares (gha). The ecological footprint of battery charging using fossil-fuel-based grid electricity is roughly  $3.1 \times 10^{-4}$  gha per kWh.

➤ *Charging Infrastructure Expansion and Grid Stress*

The rapid rise in EV adoption demands equally rapid infrastructure expansion. Public charging stations have grown significantly in recent years:

- 2023: 11,903 stations
- 2024: 25,202 public charging stations
- 2025: Over 29,277 EV charging stations
- 2030 Target: Approximately 1.32 million stations

However, expanding infrastructure places substantial stress on power grids. Increased electricity demand requires upgrades in transformers, substations, and distribution networks. Without proper planning, localized overloading and instability may occur.

Between October 1, 2024, and March 31, 2026, ₹10,900 crore has been allocated toward EV expansion in India, highlighting the financial magnitude of this transition.

➤ *Geopolitical Dependency and Supply Chain Risks*

The EV industry depends heavily on a few countries for lithium, cobalt, and nickel. This concentration creates supply chain vulnerabilities and price volatility. Political

instability or trade restrictions in key mining regions could disrupt global EV production.

Such geopolitical dependence raises strategic concerns about energy security and economic resilience. Diversification of supply chains and development of alternative battery chemistries are therefore essential.

➤ *Fire Risks and Safety Concerns*

Lithium-ion batteries carry inherent risks of thermal runaway a condition where internal reactions generate uncontrollable heat. EV fires, though statistically infrequent, are more difficult to extinguish compared to conventional vehicle fires and require specialized techniques.

Safety standards, thermal management systems, and emergency response training must evolve alongside EV adoption.

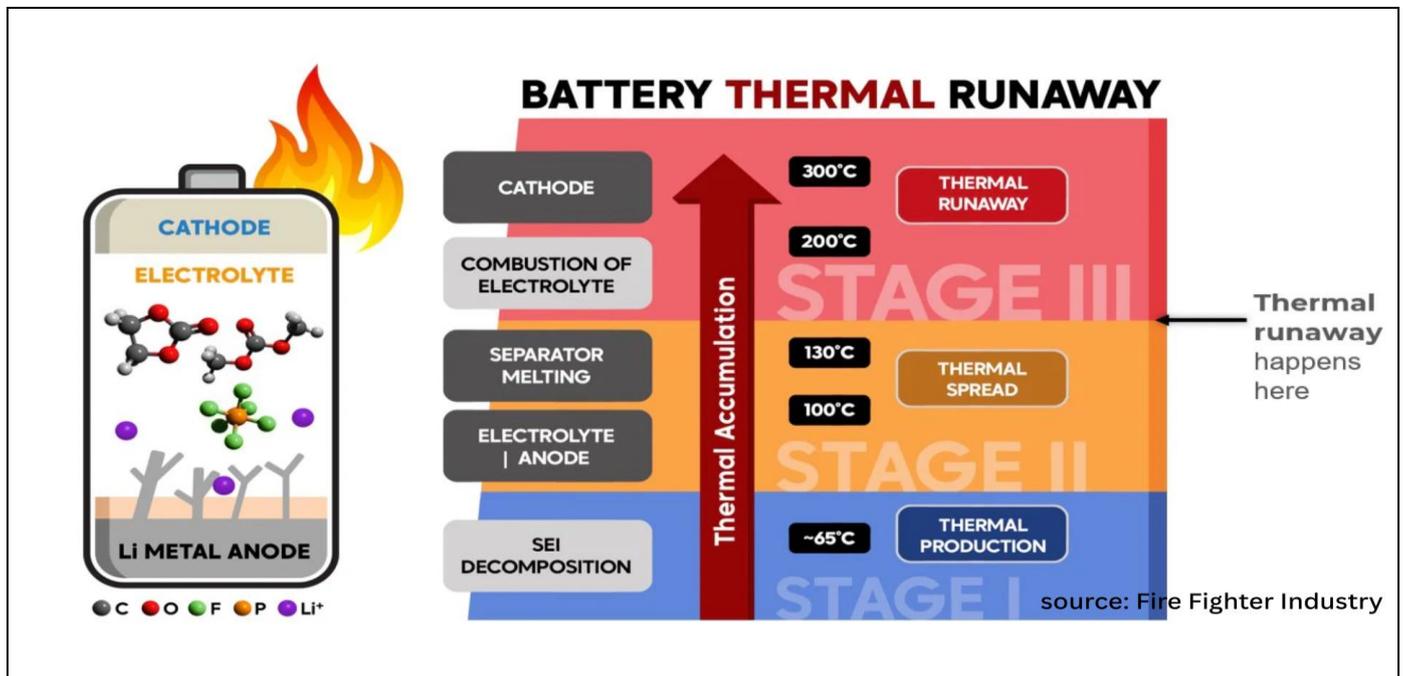


Fig 3 Concept of Thermal Runaway

➤ *Employment Shifts and Industrial Transformation*

The transition to electric mobility reduces demand for engine manufacturing, transmission systems, and oil-related industries. While new jobs emerge in battery production and renewable energy sectors, traditional automotive and fossil fuel workers may face displacement.

A just transition framework is necessary to ensure workforce retraining and economic inclusion.

➤ *EVs and the Sustainable Development Goals (SDGs)*

The environmental and socio-economic impacts of EV expansion intersect with several SDGs:

- SDG 12 (Responsible Consumption and Production): Unsustainable mining practices threaten resource efficiency and ecological balance.
- SDG 15 (Life on Land): Habitat destruction, biodiversity loss, and soil erosion arise from mining activities.
- SDG 6 (Clean Water and Sanitation): Lithium extraction reduces water tables and affects salinity levels.
- SDG 13 (Climate Action): Fossil-fuel-based grids reduce net climate benefits.
- SDG 7 (Affordable and Clean Energy): Grid stress may increase reliance on backup fossil plants.

➤ *Environmental Lessons from the COVID-19 Quarantine*

During global lockdowns, emissions fell significantly without large-scale EV deployment. This temporary improvement demonstrated the direct relationship between fossil fuel consumption and environmental quality.

However, economic activity slowed drastically. The EV transition seeks to reduce emissions without halting development. Yet, if powered by fossil-heavy grids, the transition offers only partial environmental gains. True sustainability requires systemic energy transformation.

➤ *The Path Forward: Renewable Integration and Policy Commitments*

Integrating solar photovoltaic (PV) systems with EV charging stations can reduce ecological footprint by nearly 90%, bringing annual impact down to approximately 4.14 gha.

India's climate commitments under the Panchamrit declaration at COP26 include ambitious renewable energy expansion, carbon intensity reduction, and achieving net-zero emissions by 2070. Hydrogen technologies may also provide solutions for long-distance heavy transport in the future.

### III. CONCLUSION

Electric Vehicles (EVs) represent a crucial shift toward cleaner transportation by reducing urban air pollution and eliminating tailpipe emissions; however, their overall sustainability depends on addressing lifecycle impacts beyond vehicle operation. Battery production requires intensive lithium, cobalt, and nickel mining, which contributes to water depletion, habitat destruction, and carbon emissions, while fossil-fuel-based electricity generation can limit climate benefits by shifting emissions from roads to power plants. Large-scale infrastructure expansion also increases grid stress and ecological footprint. Therefore, the long-term success of EV adoption depends on integrating renewable energy such as solar-powered charging systems implementing sustainable mining practices, strengthening battery recycling through circular economy models, and aligning with national climate commitments like renewable capacity expansion and net-zero targets. Without these structural reforms, EV growth risks externalizing environmental damage rather than fully advancing sustainable development.

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