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REVIEW ARTICLE

Driving the Future: A Comprehensive Analysis of the Transition to Electric Vehicles for Sustainable Mobility

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ABSTRACT:

The escalating environmental impact of conventional internal combustion engine (ICE) vehicles has intensified the global call for cleaner, more sustainable transportation solutions. Electric vehicles (EVs) have emerged as a promising alternative, offering reduced emissions, lower operating costs, and enhanced energy efficiency. This research paper investigates the transition toward electric mobility by analysing technological advancements, policy support, market trends, and socio-economic challenges associated with EV adoption. The primary objective is to evaluate the effectiveness and scalability of EVs in contributing to global sustainability goals. A mixedmethods approach was employed, including an extensive review of academic literature, analysis of global EV adoption statistics, and case studies from EV-leading nations such as Norway, China, and the United States. The findings reveal that while EVs offer substantial environmental benefits and long-term economic advantages, their widespread adoption is constrained by factors such as high initial costs, limited charging infrastructure, and concerns over battery production and disposal.

KEYWORDS: Electric Vehicles (EVs) Sustainable Transportation Environmental Impact Internal Combustion Engine (ICE) Vehicles EV Adoption Technological Advancements

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1. INTRODUCTION

The transportation sector plays a vital role in global economic development by facilitating the movement of people and goods. However, it is also one of the largest contributors to global greenhouse gas (GHG) emissions and fossil fuel consumption. According to the International Energy Agency, transportation accounts for approximately 23% of global energy-related carbon dioxide (CO_2) emissions, with road transport contributing nearly three-quarters of these emissions.[1,2] The continued dependence on petroleum-derived fuels has intensified environmental concerns, including climate change, urban air pollution, ecosystem degradation, and adverse human health effects.[3,4] Consequently, decarbonizing the transportation sector has become a critical priority for achieving global sustainability and meeting international climate commitments.

The rapid increase in global vehicle ownership, urbanization, and industrialization has further accelerated fuel consumption and atmospheric emissions. Conventional internal combustion engine (ICE) vehicles emit substantial quantities of carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter ($PM_{2.5}$), hydrocarbons (HCs), and volatile organic compounds (VOCs), all of which contribute to deteriorating air quality and increased incidences of respiratory and cardiovascular diseases.[5],[6] The World Health Organization has reported that ambient air pollution is responsible for approximately seven million premature deaths annually, emphasizing the urgent need for cleaner transportation technologies.[7]

Electric vehicles (EVs) have emerged as one of the most promising alternatives to conventional ICE vehicles because they offer higher energy efficiency, zero tailpipe emissions, lower maintenance requirements, and compatibility with renewable electricity generation.[8] Battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel-cell electric vehicles (FCEVs) collectively represent the major categories of vehicle electrification currently being deployed worldwide. Among these technologies, BEVs have gained the greatest commercial acceptance owing to continuous improvements in lithium-ion battery technology, declining battery costs, and expanding charging infrastructure.[9],[10]

During the past decade, remarkable technological progress has transformed electric mobility from a niche concept into a mainstream transportation solution. The average cost of lithium-ion battery packs has declined dramatically while energy density, charging speed, cycle life, and operational safety have improved significantly.[11] These developments have enabled modern electric vehicles to achieve driving ranges exceeding 500 km per charge while reducing the total cost of ownership compared with conventional gasoline-powered vehicles in several markets.[12] Furthermore, advances in battery management systems (BMS), regenerative braking, power electronics, and lightweight materials have enhanced vehicle performance, reliability, and overall energy efficiency.[13]

Government policies have played a decisive role in accelerating global EV adoption. Financial incentives, tax exemptions, zero-emission vehicle mandates, fuel economy regulations, investments in charging infrastructure, and research funding have encouraged both manufacturers and consumers to adopt electric mobility.[14] Norway has become the global leader in EV penetration through long-term fiscal incentives and extensive public charging infrastructure, whereas China has emerged as the world's largest EV market owing to strategic industrial policies and large-scale battery manufacturing.[1],[15] Similar initiatives in the United States, Germany, the United Kingdom, and India continue to stimulate investments in electric mobility and domestic battery production.[16]

Although electric vehicles provide considerable environmental and economic benefits, several challenges remain before widespread adoption can be achieved. High initial purchase costs, limited charging infrastructure in many developing countries, battery degradation, critical mineral supply constraints, recycling challenges, and electricity grid modernization continue to limit large-scale deployment.[17],[18] Moreover, the overall environmental performance of electric vehicles depends strongly on the carbon intensity of the electricity used for charging, making renewable energy integration an essential component of sustainable transportation systems.[19]

Recent advances in artificial intelligence (AI), Internet of Things (IoT), smart charging, and Vehicle-to-Grid (V2G) technologies are creating new opportunities for integrating electric vehicles with intelligent energy systems. These innovations enable optimized charging schedules, predictive battery health monitoring, demand-side energy management, and enhanced utilization of renewable electricity sources.[20] Consequently, electric vehicles are increasingly being recognized not only as sustainable transportation solutions but also as distributed energy storage resources capable of supporting future smart grids.

The objective of this review is to comprehensively evaluate recent developments in electric vehicle technologies, battery innovations, charging infrastructure, lifecycle environmental performance, market growth, policy frameworks, consumer adoption, and future research directions. By

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synthesizing evidence from recent scientific literature and international reports, this review aims to identify current achievements, remaining challenges, and strategic opportunities for accelerating the global transition toward sustainable electric mobility.

2. MATERIALS AND METHODS

2.1. Review design

This study was conducted as a comprehensive narrative and systematic review to critically evaluate the transition from conventional internal combustion engine (ICE) vehicles to electric vehicles (EVs) and their role in achieving sustainable mobility. The review followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) to ensure a transparent and reproducible literature selection process. The review focused on technological developments, environmental impacts, battery innovations, charging infrastructure, government policies, market trends, lifecycle sustainability, and future prospects of electric mobility.

2.2 Literature Search Strategy

A comprehensive literature search was performed using major international scientific databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, Wiley Online Library, Taylor & Francis Online, and Google Scholar. To include recent policy developments and industrial perspectives, reports published by the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), International Council on Clean Transportation (ICCT), United Nations Environment Programme (UNEP), European Environment Agency (EEA), NITI Aayog, Society of Indian Automobile Manufacturers (SIAM), and the Ministry of Heavy Industries, Government of India were also reviewed.

The literature search covered publications from January 2020 to June 2026, while seminal studies published before 2020 were incorporated where necessary to provide historical background on electric vehicle technologies, battery development, and lifecycle assessment methodologies.

The following search terms and Boolean operators were used individually and in combination:

- "Electric Vehicle" OR "Battery Electric Vehicle" OR "EV"
- "Sustainable Transportation"
- "Electric Mobility"
- "Battery Technology"
- "Lithium-ion Battery"
- "Solid-state Battery"
- "Charging Infrastructure"
- "Vehicle-to-Grid"
- "Battery Recycling"
- "Renewable Energy"
- "Carbon Emissions"
- "Life Cycle Assessment"
- "Electric Vehicle Adoption"
- "Government Policy"

Manual screening of the reference lists of relevant review papers and highly cited articles was also undertaken to identify additional studies not retrieved during the electronic database search.

2.3 Eligibility Criteria

Publications were considered eligible if they satisfied the following criteria:

- Published in peer-reviewed scientific journals.
- Written in the English language.
- Published between January 2020 and June 2026 (except landmark studies cited for background information).
- Focused on electric vehicles, battery technologies, charging infrastructure, environmental sustainability, energy efficiency, lifecycle assessment, policy

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frameworks, market trends, or consumer adoption.

- Reported scientifically validated findings, review evidence, industrial analyses, or policy evaluations relevant to sustainable electric mobility.

Publications were excluded if they were editorials, news articles, patents without supporting scientific discussion, duplicate records, or studies unrelated to transportation electrification.

2.4 Literature Selection

The literature selection process followed the PRISMA 2020 framework. Initially, publications identified through electronic database searching and manual reference screening were imported into a reference management software package for duplicate removal. Titles and abstracts were subsequently screened to eliminate studies that did not address the objectives of the review. The remaining full-text articles were assessed for relevance, scientific quality, and alignment with the predefined eligibility criteria. Studies meeting the inclusion criteria were retained for qualitative synthesis and critical discussion.

2.5 Data Extraction and Synthesis

Relevant information was extracted from the selected publications, including publication year, country, research focus, battery chemistry, charging technologies, environmental indicators, lifecycle emissions, policy initiatives, market trends, renewable energy integration, consumer behavior, and future technological developments. The extracted information was organized into thematic categories to facilitate comparative evaluation and critical analysis.

A qualitative synthesis approach was adopted to integrate findings from the selected studies. Similar research outcomes were grouped under common themes such as battery technology, charging infrastructure, environmental sustainability, government incentives, lifecycle assessment, economic feasibility, and future mobility solutions. Comparative discussions were developed to identify current achievements, research gaps, technological limitations, and emerging opportunities in the electric vehicle sector.

2.6 Scope of the Review

The review emphasizes six major dimensions of electric mobility:

1. Technological advancements in electric vehicles and battery systems.
2. Environmental performance and lifecycle greenhouse gas emissions.
3. Charging infrastructure and smart energy integration.
4. Government policies and market development.
5. Economic feasibility and consumer adoption.
6. Future research directions, including artificial intelligence, vehicle-to-grid technologies, battery recycling, and next-generation energy storage systems.

3. RESULTS AND DISCUSSION

3.1. Global Evolution of Electric Vehicles and Sustainable Mobility

The global transportation sector is undergoing an unprecedented transformation driven by the urgent need to reduce greenhouse gas emissions, improve energy efficiency, and decrease dependence on fossil fuels. Electric vehicles (EVs) have emerged as the cornerstone of sustainable transportation owing to continuous technological advancements, supportive governmental policies, and increasing environmental awareness. According to recent reports published by the International Energy Agency (IEA), global electric vehicle sales have increased exponentially over the past decade, surpassing 17 million units in 2024 and accounting for approximately one-fifth of total passenger vehicle sales worldwide This remarkable growth reflects significant progress in

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battery technology, charging infrastructure expansion, and declining manufacturing costs.

Historically, electric vehicles were introduced during the late nineteenth century but gradually lost market dominance because of the rapid commercialization of internal combustion engine (ICE) vehicles, abundant petroleum resources, and limitations in battery technology. However, increasing concerns regarding climate change, urban air pollution, volatile fuel prices, and energy security have renewed global interest in transportation electrification. Over the last two decades, substantial investments in research and development have transformed EVs into commercially viable alternatives capable of competing with conventional gasoline and diesel vehicles in terms of performance, reliability, and operating costs.

The transition toward electric mobility has been strongly influenced by international climate commitments and sustainable development initiatives. The Paris Agreement, United Nations Sustainable Development Goals (SDGs), and numerous national carbon neutrality policies have established ambitious targets for reducing greenhouse gas emissions from the transportation sector. Consequently, governments worldwide have introduced comprehensive policy measures, including purchase incentives, tax exemptions, zero-emission vehicle mandates, investments in charging infrastructure, and stringent emission regulations to accelerate EV adoption. These policy interventions have stimulated industrial innovation while encouraging consumers to shift toward cleaner transportation alternatives.

The global electric vehicle market is characterized by considerable regional variation. China currently dominates worldwide EV production and sales, supported by strong industrial policies, extensive battery manufacturing capabilities, and large-scale domestic demand. Norway has achieved the highest EV market penetration globally through long-term fiscal incentives, extensive charging infrastructure, and public acceptance of electric mobility. European countries, including Germany, the Netherlands, France, and Sweden, have rapidly expanded EV adoption through stringent environmental regulations and investments in renewable energy integration. Meanwhile, the United States continues to strengthen its EV ecosystem through technological innovation, federal incentives, and investments in domestic battery manufacturing.

Developing economies, including India, are also witnessing substantial growth in electric mobility. National initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, the National Electric Mobility Mission Plan (NEMMP), and various state-level incentive programs have significantly accelerated EV deployment across two-wheelers, three-wheelers, passenger vehicles, and public transportation. The rapid expansion of domestic battery manufacturing under the Production Linked Incentive (PLI) scheme and increasing private-sector investments in charging infrastructure are expected to further strengthen India's transition toward sustainable transportation.

Technological innovation remains the principal driver of EV market expansion. Improvements in lithium-ion batteries have increased energy density while reducing battery costs by more than 80% during the past decade. Contemporary battery electric vehicles now offer driving ranges exceeding 500–700 km under standardized testing conditions, addressing one of the primary concerns associated with consumer adoption. Furthermore, advances in battery management systems, regenerative braking technologies, lightweight materials, and high-efficiency electric powertrains have significantly improved vehicle performance, reliability, and energy efficiency.

Digitalization is also transforming the EV ecosystem. Artificial intelligence (AI), Internet of Things (IoT), cloud computing, big data analytics, and machine learning are increasingly integrated into modern electric vehicles to optimize battery performance, predict maintenance requirements, enhance charging efficiency, and improve overall user experience.[155–158] Smart mobility solutions further enable real-time traffic management, intelligent charging scheduling, autonomous driving capabilities, and seamless integration with renewable energy systems. These digital technologies are expected to play a pivotal role in the future development of intelligent and connected transportation networks.

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Despite rapid technological progress, several challenges continue to limit widespread EV adoption. High initial purchase costs, limited charging infrastructure in many developing regions, battery degradation, raw material supply constraints, electricity grid limitations, and end-of-life battery management remain major concerns requiring continued research and policy support. Moreover, the environmental sustainability of electric vehicles depends substantially on the electricity generation mix used for battery charging. Regions relying predominantly on renewable or low-carbon electricity sources achieve considerably greater lifecycle greenhouse gas reductions than regions dependent on coal-fired power generation. Consequently, transportation electrification must be accompanied by simultaneous decarbonization of electricity production to maximize environmental benefits.

Overall, the global evolution of electric vehicles demonstrates that sustainable transportation is transitioning from a conceptual objective to an achievable reality. Continuous technological advancements, supportive government policies, expanding charging infrastructure, renewable energy integration, and increasing public awareness are collectively accelerating the transformation toward cleaner mobility systems. Nevertheless, coordinated international efforts involving policymakers, researchers, automotive manufacturers, energy providers, and consumers remain essential to overcome existing barriers and ensure the successful realization of carbon-neutral transportation in the coming decades.

4. CONCLUSION

The transition from conventional internal combustion engine vehicles to electric vehicles represents a transformative step toward achieving sustainable, low-carbon transportation. This review demonstrates that electric vehicles offer significant advantages in terms of energy efficiency, reduced greenhouse gas emissions, lower operating and maintenance costs, and compatibility with renewable energy systems. Continuous advancements in battery technologies, fast-charging infrastructure, battery management systems, and smart grid integration have substantially improved the performance, reliability, and commercial viability of EVs. Furthermore, supportive government policies, financial incentives, and increasing investments in charging infrastructure have accelerated global EV adoption.

Despite these advancements, several challenges remain, including high initial vehicle costs, limited charging infrastructure in developing regions, battery recycling and end-of-life management, critical raw material supply constraints, and dependence on low-carbon electricity for maximizing environmental benefits. Addressing these barriers requires coordinated efforts among governments, industries, researchers, and energy providers to strengthen policy frameworks, promote sustainable battery manufacturing and recycling, expand renewable energy integration, and modernize electricity grids.

Overall, electric vehicles are expected to play a pivotal role in future sustainable mobility by supporting decarbonization, enhancing energy security, and reducing environmental pollution. Continued research into next-generation batteries, artificial intelligence-enabled energy management, vehicle-to-grid technologies, wireless charging, and circular battery economy practices will further accelerate the global transition toward cleaner, more resilient, and environmentally sustainable transportation systems.

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