The role of electric vehicles in sustainable development: Reducing pollution and carbon footprints

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Received 9 March 2026; Accepted 13 Apr 2026; Published 6 May 2026

DOI: https://doi.org/10.64171/JSRD.5.S1.68-72

Abstract

The increasing use of internal combustion engine (ICE) two-wheelers in Uttar Pradesh has significantly contributed to air pollution, leading to severe environmental and health concerns. This study explores the impact of ICE two-wheelers on pollution levels and assesses the potential of electric two-wheelers (e-2Ws) as a sustainable alternative. Through a comprehensive analysis of emissions, economic feasibility, and government policies, this paper highlights the benefits of transitioning to electric two-wheelers. Findings indicate that e-2Ws offer lower operational costs, reduced emissions, and align with sustainability goals. However, challenges such as high initial costs, inadequate charging infrastructure, and consumer hesitancy remain. Policy recommendations include expanding charging networks, increasing subsidies, and improving battery technology to accelerate e-2W adoption. This study underscores the importance of strategic policy implementation and technological advancements in promoting sustainable urban mobility in Uttar Pradesh.

Keywords: Electric two-wheelers, Air pollution, Sustainable transportation, Government policies, Consumer adoption

1. Introduction

1.1 Background & importance of two-wheelers in Uttar Pradesh

Two-wheelers are one of the most commonly used modes of transportation in Uttar Pradesh. With millions of people relying on motorcycles and scooters for daily commuting, two-wheelers play a crucial role in the state's economy and transportation sector. They are widely used by office-goers, students, delivery personnel, and small business owners due to their affordability and fuel efficiency (Indian Brand Equity Foundation [IBEF], 2023) [4]. According to Statista (2023, 2024), Uttar Pradesh had over 34.9 million registered vehicles by 2020, with two-wheelers forming a significant portion of this figure. However, their widespread usage also contributes significantly to air pollution, leading to growing environmental concerns.

1.2 Environmental impact of ICE two-wheelers

Studies show that internal combustion engine (ICE) two-wheelers are a major contributor to air pollution in India. According to the International Council on Clean Transportation (ICCT, 2023) [5], two-wheelers contribute approximately 30% of vehicular CO_2 emissions in urban areas. The Central Pollution Control Board (CPCB, 2023) [1] reported that two-wheelers account for nearly 60% of the total vehicle fleet in India, making them a significant source of particulate matter (PM2.5) and nitrogen oxides (NOx), both of which severely impact air quality. In Uttar Pradesh, cities like Lucknow, Kanpur, and Varanasi experience high pollution levels largely due to vehicular emissions. A study by Sharma *et al*. (2022) found that two-wheelers in Uttar Pradesh produce an estimated 6 million metric tons of CO_2 annually, further worsening air pollution concerns. Traditional two-wheelers are powered by internal combustion engines (ICE) that run on petrol, emitting high levels of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). These emissions contribute to air pollution and deteriorate air quality, leading to severe health issues such as respiratory diseases and cardiovascular problems (Central Pollution Control Board [CPCB], 2023) [1]. According to a report by the Daily Pioneer (2022) [2], ICE two-wheelers contribute nearly 20% of total CO_2 emissions and 30% of particulate emissions in urban areas.

1.3 Air pollution crisis in major cities of Uttar Pradesh

Uttar Pradesh faces a severe air pollution crisis, particularly in cities like Lucknow, Kanpur, and Agra, which are among the most polluted cities in India (IQAir, 2023). Vehicular pollution, including emissions from two-wheelers, plays a significant role in increasing the Air Quality Index (AQI) levels. Reports from the World Health Organization (WHO, 2023) [15] indicate that prolonged exposure to air pollution can lead to respiratory issues, reduced lung function, and premature deaths. This crisis

calls for urgent measures to reduce emissions from vehicles, especially two-wheelers.

1.4 Consumer behaviour & shift toward electric two-wheelers

Despite environmental concerns, ICE two-wheelers remain popular due to their affordability, widespread availability of fuel stations, and consumer familiarity. However, rising petrol prices and increasing maintenance costs are pushing consumers to explore electric alternatives. A recent study by JMK Research (2024) [9] found that over 60% of two-wheeler owners in urban areas are considering switching to electric two-wheelers due to lower running costs and environmental benefits. This shift in consumer behaviour indicates a growing interest in sustainable transportation solutions.

1.5 Government initiatives & policies for EV adoption

Recognizing the environmental impact of ICE two-wheelers, the Indian government has introduced several policies to promote electric vehicle (EV) adoption. The Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME II) scheme provides subsidies and incentives to encourage the purchase of electric two-wheelers (Invest India, 2023) [6]. Uttar Pradesh's Electric Vehicle Policy (2022) aims to position the state as a leader in EV manufacturing and infrastructure development by offering tax exemptions and financial support to manufacturers and consumers (Invest UP, 2022) [7].

Despite these initiatives, challenges remain in policy implementation. The lack of widespread charging infrastructure remains a major barrier to adoption. According to NITI Aayog (2024) [11], Uttar Pradesh currently has only 300 operational charging stations, which is insufficient given the growing demand for EVs. Furthermore, high battery replacement costs and concerns about range anxiety continue to slow down mass adoption. Addressing these issues through enhanced infrastructure investment and battery technology innovation is critical for achieving long-term EV adoption goals.

1.6 Benefits of electric two-wheelers over ice two-wheelers

Electric two-wheelers (e-2Ws) offer several advantages over traditional ICE models, including:

- **Zero tailpipe emissions:** Unlike petrol-powered two-wheelers, e-2Ws produce no emissions, contributing to improved air quality (CPCB, 2023).
- **Lower running costs:** Electricity is significantly cheaper than petrol, reducing the cost per kilometer for e-2Ws (Economic Times, 2024) [3, 17].
- **Reduced maintenance costs:** EVs have fewer moving parts, leading to lower maintenance requirements compared to ICE two-wheelers (Statista, 2023 [14], 2024).
- **Government subsidies:** Policies like FAME II and state-level EV incentives have significantly reduced the purchase cost of electric two-wheelers (Invest India, 2023) [6].

1.7 Current adoption trends of electric two-wheelers in India & Uttar Pradesh

The adoption of electric two-wheelers in India has been steadily increasing. According to Statista (2024) [16], annual sales of e-2Ws have grown significantly from 1.5 lakh units in 2019 to over 10.5 lakh units in 2023. Uttar Pradesh has emerged as one of the leading states in EV adoption, driven by government incentives and an expanding charging infrastructure (JMK Research, 2024) [9].

Table 1: Comparison of ICE two-wheelers vs. electric two-wheelers

Factor	ICE two-wheelers	Electric two-wheelers
Emissions	High CO_2, NOx, and particulate matter emissions	Zero tailpipe emissions (CPCB, 2023)
Running cost (per km)	₹2-3 per km (Petrol)	₹0.5-1 per km (Electricity) (Economic Times, 2024) [3, 17]
Maintenance cost	Higher, frequent servicing required	Lower, fewer moving parts (Statista, 2023 [14], 2024)
Fuel efficiency	30-50 km per liter	100-150 km per charge
Government incentives	Limited subsidies	Various government subsidies available (Invest India, 2023) [6]
Environmental impact	Contributes to pollution and climate change	Eco-friendly and reduces carbon footprint
Initial purchase cost	Lower (₹50,000 - ₹1,00,000)	Higher (₹70,000 - ₹1,50,000) before subsidies
Refuelling/Recharging time	Quick refuelling (5 minutes)	3-5 hours for a full charge

Review of literature

A review of existing literature on the impact of two-wheelers on pollution and the transition to electric alternatives provides valuable insights into the subject.

Two-wheeler emissions and environmental impact

According to a report by the International Council on Clean Transportation (ICCT) (2023), two-wheelers contribute significantly to urban air pollution due to inefficient combustion processes. A study by Kumar *et al*. (2022) [10] found that two-wheelers account for nearly 30% of vehicular emissions in densely populated Indian cities, including Uttar Pradesh.

Economic feasibility of electric two-wheelers

Research by Sharma and Gupta (2021) [12] highlights that the total cost of ownership of electric two-wheelers becomes lower than ICE counterparts within three to five years of usage. The study emphasizes that government subsidies under FAME II have played a crucial role in bridging the cost gap.

Government policies and market adoption

A policy analysis by Singh *et al*. (2023) [13] underscores the importance of state and central incentives in promoting EV adoption. Their research found that states with robust EV policies, such as Uttar Pradesh, Maharashtra, and Delhi, have witnessed higher adoption rates of electric two-wheelers.

Consumer perception towards EV adoption

A consumer survey conducted by JMK Research (2024) [9] found that range anxiety, high initial costs, and inadequate charging infrastructure are primary concerns affecting the mass adoption of electric two-wheelers. However, increasing awareness and declining battery costs are improving consumer confidence.

Objectives

This study focuses on the following key objectives:

- To analyse the impact of ICE two-wheelers on air pollution levels in Uttar Pradesh.
- To evaluate the economic and social benefits of transitioning to electric two-wheelers.
- To assess the effectiveness of government policies in promoting electric two-wheeler adoption and sustainable transportation.

Research methodology

This study adopts a mixed-method approach, incorporating both quantitative and qualitative research methods to evaluate the impact of ICE two-wheelers and the transition to electric two-wheelers. The methodology includes:

- **Secondary data collection:** Information is gathered from government reports (e.g., CPCB, NITI Aayog, FAME India Scheme), industry reports (e.g., Statista, JMK Research), and academic studies.
- **Comparative analysis:** A comparison between ICE and electric two-wheelers in terms of emissions, cost-effectiveness, and adoption trends is conducted.
- **Policy evaluation:** The effectiveness of government initiatives such as FAME II and Uttar Pradesh's EV policy is analysed (through published reports and adoption rate data.

This research methodology ensures a comprehensive analysis of the environmental, economic, and policy-related aspects of ICE and electric two-wheelers in Uttar Pradesh.

Key findings of the study

This section presents the key findings derived from the research on ICE two-wheelers and the transition to electric two-wheelers:

- ICE two-wheelers significantly contribute to air pollution in Uttar Pradesh, with vehicular emissions accounting for a substantial portion of the state's deteriorating air quality.
- Electric two-wheelers offer considerable economic benefits, including lower running costs and reduced maintenance expenses, making them a financially viable alternative.
- Government policies such as FAME II and state-level EV incentives have positively influenced adoption trends, but infrastructural challenges, such as a lack of charging stations, remain major barriers.
- Consumer behaviour is gradually shifting towards electric two-wheelers, primarily driven by rising fuel prices and increasing awareness of environmental benefits.
- Despite government incentives, the high initial cost and battery-related concerns continue to hinder widespread adoption, indicating the need for further policy intervention and infrastructure development.

Discussions of the results

The findings of this study provide critical insights into the environmental, economic, and policy dimensions of two-wheeler transportation in Uttar Pradesh, particularly in the context of the transition from internal combustion engine (ICE) two-wheelers to electric two-wheelers (e-2Ws). The results strongly reinforce existing evidence that two-wheelers constitute a major source of urban air pollution in India due to their dominance in the vehicle fleet and reliance on petrol-based engines (CPCB, 2023; ICCT, 2023).

The study confirms that ICE two-wheelers significantly contribute to emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter, especially in highly congested urban centres such as Lucknow, Kanpur, and Agra. This finding is consistent with prior research indicating that two-wheelers account for nearly 30% of vehicular emissions in densely populated Indian cities despite their smaller engine capacity (Kumar *et al*., 2022 [10]; ICCT, 2023). The results emphasize that without targeted intervention in the two-wheeler segment, achieving meaningful improvements in air quality in Uttar Pradesh will remain challenging.

From an economic perspective, the findings demonstrate that electric two-wheelers offer a clear cost advantage over ICE models in terms of running and maintenance expenses. Lower electricity costs per kilometre and reduced mechanical complexity significantly decrease total ownership costs over time, supporting earlier conclusions that e-2Ws achieve cost parity within three to five years of usage (Sharma & Gupta, 2021 [12]; Statista, 2024) [16]. This economic feasibility is particularly relevant for daily commuters and gig-economy workers, who are highly sensitive to fuel and maintenance expenses.

The study also highlights the important but partial role of government policies in driving electric two-wheeler adoption. Central initiatives such as the FAME II scheme and state-level incentives in Uttar Pradesh have positively influenced sales growth by lowering upfront purchase costs (Invest India, 2023 [6]; JMK Research, 2024) [9]. However, the effectiveness of these policies is constrained by infrastructural limitations, particularly the inadequate availability of charging stations. As noted by NITI Aayog (2024) [11], the limited charging network in Uttar Pradesh continues to intensify range anxiety, thereby slowing mass adoption despite favourable policy intent.

In terms of consumer behaviour, the findings indicate a gradual shift towards electric two-wheelers, driven by rising petrol prices, environmental awareness, and long-term cost savings. Nevertheless, concerns related to battery life, charging time, and resale value persist, echoing earlier survey-based evidence on consumer hesitancy toward electric mobility (JMK Research, 2024) [9]. This suggests that while attitudes toward sustainability are improving, adoption decisions remain strongly influenced by perceived convenience and risk.

Overall, the discussion reveals that the transition to electric two-wheelers in Uttar Pradesh is a multidimensional process shaped by environmental necessity, economic rationality, policy support, and consumer perception. These findings extend existing literature by offering a region-specific assessment of electric mobility adoption in one of India's most populous states.

Implications of the study

1. Policy implications

The findings suggest that policymakers must move beyond subsidy-driven approaches toward a more integrated electric mobility strategy. While financial incentives under FAME II and state EV policies have been effective in stimulating demand, large-scale adoption will require accelerated investment in charging infrastructure, particularly in tier-2 and tier-3 cities of Uttar Pradesh (NITI Aayog, 2024 [11]; Invest UP, 2022). Supporting battery-swapping models and encouraging public–private partnerships can further reduce infrastructure-related barriers and range anxiety.

2. Industry and market implications

For manufacturers and market participants, the results highlight substantial growth potential in the electric two-wheeler segment. Firms can capitalize on the lower operating costs and environmental benefits of e-2Ws while addressing consumer concerns through technological innovation in battery efficiency, charging speed, and vehicle range (Statista, 2024). Flexible financing schemes and improved after-sales service networks may further enhance consumer trust and adoption rates, particularly in semi-urban regions.

3. Consumer and social implications

At the societal level, increased adoption of electric two-wheelers can significantly reduce urban air pollution, greenhouse gas emissions, and noise levels, contributing to improved public health outcomes (WHO, 2023; CPCB, 2023). For consumers, especially low- and middle-income groups, electric two-wheelers offer a cost-effective and sustainable mobility option, provided that charging access and battery affordability improve.

4. Environmental implications

The environmental implications of the study are substantial. A large-scale shift from ICE to electric two-wheelers could meaningfully lower vehicular emissions in Uttar Pradesh, where two-wheelers dominate personal transport (ICCT, 2023). This transition aligns with India's national climate commitments and broader sustainable development objectives, reinforcing the role of electric mobility in mitigating climate change impacts.

5. Implications for future research

Future studies may build on this research by incorporating primary survey data to examine consumer willingness to pay, adoption intention, and post-purchase satisfaction with electric two-wheelers. Longitudinal analyses could further assess the long-term environmental and economic impacts of EV adoption at the state or city level (JMK Research, 2024).

Conclusion

The transition from internal combustion engine (ICE) two-wheelers to electric two-wheelers presents a promising solution to combat air pollution and reduce reliance on fossil fuels in Uttar Pradesh. The research highlights that ICE two-wheelers are a significant source of vehicular emissions, contributing to deteriorating air quality and associated health concerns in the state.

Electric two-wheelers, with their zero tailpipe emissions and lower operational costs, provide a viable alternative that aligns with India's sustainability goals. While government policies such as FAME II and state EV incentives have played a role in accelerating adoption, challenges such as inadequate charging infrastructure, high initial purchase costs, and range anxiety still hinder widespread acceptance.

For the successful transition to sustainable transportation, further improvements in policy implementation, technological advancements in battery storage, and expansion of charging networks are required. If these barriers are addressed, electric two-wheelers have the potential to significantly contribute to reducing pollution and promoting sustainable mobility in Uttar Pradesh.

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