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AN ANALYTICAL STUDY OF ADOPTION CHALLENGES AND FUTURE PROSPECTS OF FOUR-WHEELER ELECTRIC VEHICLES IN PUNE CITY: A TECHNO-INFRASTRUCTURE AND CONSUMER BEHAVIOUR PERSPECTIVE

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ABSTRACT
The present research is a discussion on factors influencing the adoption of electric four-wheelers in a new urban mobility ecosystem. The research adheres to a quantitative research design, which is descriptive-analytical, and a structured questionnaire, distributed to 415 owners of EV vehicles in Pune, is used. The reliability, validity, and adequacy of the sampling tests proved the data's suitability, and were then tested using regression and structural path analyses. These findings indicate that techno-infrastructural readiness in particular in terms of charging, battery range, and service networks produce a strong impact on intention to adopt. The positive influencing variables in purchase decisions are those concerning consumer behaviour, such as environmental concern, cost-savings perception, and awareness of subsidies; the negative variable is resale uncertainty. Besides, AI-driven features, interconnected car technology, and high-level systems of driver assistance have a massive positive effect on the likelihood of implementing them in the future. The study concludes by stating that even though Pune is market prepared, immediate infrastructure development, financial incentives and smart mobility integration would be required to sustain mass four-wheeler EV diffusion and enable India to emerge a sustainable city transportation system.

I. INTRODUCTION

Due to decarbonization requirements, energy security factor, and the rapid technological advancement, the world automotive market is changing in its structure. EVs, in particular, the four-wheeler passenger category, is turning out to be a strategic measure to reduce greenhouse gas emissions, the dependence of fossil fuels and air pollution in the cities. It is established that governments worldwide are launching regulatory incentives, and carbon targets, and electrification strategies to facilitate the use of EVs. The policy efforts, such as FAME (Faster Adoption and Manufacturing of Electric Vehicles), state EV policies, and production-based incentives are driving market growth in India.

Pune City is among the largest car and technological centers in India with large automotive, electric vehicle startups, information technology firms and research and development centers. Its trend of urban mobility ecosystem of higher levels of income, environmental awareness, traffic jam and smart-city projects, predisposes it to a suitable laboratory where to test the dynamics of four-wheeler EV adoption. With the positive policy support, the procedure of replacing Internal Combustion Engine (ICE) cars with the application of electric four-wheelers is slow.

Secondly, various techno-infrastructural obstacles that still stand in the way of adoption also include the bad health of public charging facilities, battery replacement and cost, range anxiety, grid load management, and service ecosystems. The perceived cost savings, environmentally conscious, trust in the technology, uncertainty about reselling the product, and brand reliability have influence on the purchase intention, based on the consumer behaviour aspect. Moreover, new technological integrations, as well as Artificial Intelligence (AI), connected vehicle, telematics, and Advanced Driver Assistance Systems (ADAS), are changing the EV value proposition, yet new cybersecurity, data privacy, and usability concerns arise.

Because Pune is in transition of transforming smart mobility environment, the three overlapping infrastructural preparedness, technology acceptance, and consumer perceptions should be identified to forecast the EV diffusion. The current research project is an analytical investigation on the constraints of adoption and future expansion prospects of four-wheeler EVs in Pune through the application of technology-infrastructure variables and the determinants of behaviour. These outcomes are expected to assist the policymakers, manufacturers, city planners, and mobility services providers, with the development of evidence-based plan to electrify cities according to the goals of sustainable urban transport.

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II. LITTERATURE REVIEW

(Heidari, 2026) focuses on examining privacy preserving systems in AI-enabled autonomous vehicles (IoAV). The study identifies the flaws of the connected EV systems, specifically, the exchange of the information among cars, infrastructure, and the cloud. It identifies the future of protection by the use of encryption, federated learning, and blockchain. Regulatory gaps and technological preparedness issues, and the area of focus particularly those that surround the expansion of AI-empowered four-wheeler autonomous mobility markets in any region of the globe, and emerging economies.

(Nankai Business Review International, 2026) The article lists strategic alliances, data monetization, and networks of innovations as the origins of future growth and regulatory, cybersecurity, and infrastructure bottlenecks as the issue affecting the four-wheeler autonomous EV commercialization in the entire world.

(Zhu, 2025) The use of large language models (LLMs) in autonomous driving systems is addressed recently. The study outlines how the contextual reasoning, decision interpretability, and human-vehicle interaction can be enhanced with the help of the LLMs. Hallucination and real time processing constraints risks are not, however, discussed as well as safety validation. The article is a sign of AI possibilities being revolutionary in the four-wheeler EV autonomy, yet it states that hybrid validation procedures and regulatory testing areas should exist.

(Hou, 2025) As an attempt to enhance explainable autonomous driving behavior, Hou and others propose a hybrid system, vision cameras and large language models, DriveLLM-V. The framework improves the interpretability and situational awareness in complex situations of traffic. It is suggested to be used in urban four-wheeler EV navigation, however, it is reported that it has operational problems of computational intensity and sensor fusion reliability when used in the mass market.

(Ballingall & Sweatman, 2025) address fatal crashes under the investigations of automated driving systems. The most critical failures found during the study are perception errors, edge-case misjudgment, and delays related to human override errors.

(Torens, 2025) The autonomous vehicles have runtime monitoring systems, which (Torens, 2025) is concerning to determine whether the vehicles are operating within the established Operational Design Domains (ODDs). The paper demonstrates that safety and regulatory compliance can be enhanced with the help of real-time boundary detection. It can be applied particularly to the application of four-wheeler EV autonomy in a heterogeneous traffic system like in India where environmental uncertainty is a challenge to the AI driving algorithms.

(Hu, 2025) The paper presents the progress in sensor fusion, trajectory prediction, and behavioral modeling with deep neural networks. Although it has become more accurate, scalable, explainable, and adaptable to real-world settings, accuracy, scalability, explainability, and real-world adaptability are still technological challenges, especially when the goal is to commercially deploy AI-powered four-wheeler EV autonomy in the emerging mobility markets.

(Kurunathan & Jonsson, 2025) the authors examine cybersecurity models of Internet of Autonomous Vehicles with lightweight authentication schemes. The paper lays emphasis on the necessity of energy efficient encryption that befits EV architectures. It singles out hacking, spoofing, and V2X intrusion as high-risk issues. The results are important to the achievement of AI-supported four-wheeler EV ecosystems due to the increasing connectivity across the world.

(Sarangi, 2025) Behavioral intention is a mediating variable that is analyzed in to determine the adoption of EVs. The analysis combines psychological and economic factors as well as policy factors that influence consumer decision-making. It concludes that infrastructure confidence and perceived technological reliability play a substantial role in predisposing four-wheeler EVs purchase intention, which provides policy implications on how to drive EV adoption in an emerging market such as India.

(Dias, 2025) determines the intrinsic and extrinsic motivation drivers on EV adoption behavior. Cost-saving, environmental concern, and technological attractiveness are revealed as the most important factors that drive adoption. Nevertheless, range anxiety, charging delays and resale uncertainties remain as barriers to diffusion of four-wheeler EV. The research highlights the importance of combined incentive, infrastructure and awareness measures.

(Yadav, 2024) study the consumer preparedness towards EV adoption in India using the behavioural, financial, and infrastructural determinants. The research cites high buying price, fear of charge, and lack of

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familiarity to the technology as some of the discouraging factors, especially in the four-wheeler category. It was identified that policy incentives, subsidies, and awareness campaigns have a strong moderating effect on adoption intentions, which can be used strategically to develop the Indian passenger EV ecosystem.

(Barman & Dutta, 2024) The paper focuses on fast-charging corridors, urban clustering, and public-private partnerships as the key growth facilitators. The insufficiency of infrastructure is one of the main obstacles to the development of four-wheeler EVs, especially their intercity transport and electrification of commercial fleets.

(Kim, 2024) Assess the safety of autonomous driving in mixed-traffic areas of operation. Their results show that human unpredictable driving patterns and environmental variability have a huge impact on the accuracy of AI decisions. The study emphasizes the necessity of region-based safety calibrations, particularly in the application of autonomous four-wheeler EVs in the emerging markets with heterogenous traffic conditions.

(Pali, 2024) Investigates cybersecurity risks of autonomous vehicles, in particular, AI control systems, sensor spoofing, and breaches of vehicle communications. The research suggests future protection mechanisms which are blockchain authentication and intrusion detection systems. Security assurance is found as one of the requirements of consumer trust and regulatory acceptance in four-wheeler autonomous EV markets.

(Xu, 2024) Designs a reinforcement learning-based autonomous driving decision model that improves the efficiency of navigation and the accuracy of obstacle response. The study shows better lane-keeping and adaptive speed control under simulated environments. Nonetheless, four-wheeler EV autonomy is yet to be solved due to the complexities of real-world deployment, in particular, in congested urban traffic.

(Gupta, 2024) explores socio-economic and technological factors that shape the intention to use EVs. The paper shows that environmental concern, fuel saving, and technological innovation positively influence the adoption, whereas the uncertainty of maintenance and the price of

battery replacement is a deterrent to the purchase of four-wheeler EVs. Financing mechanisms and policy frameworks were suggested to overcome the affordability gaps.

(Chib & Singh, 2024) review deep learning architectures driving end-to-end autonomous driving. The article singles out the advances in convolutional neural networks, transformer models, and sensor fusion to enhance the accuracy of perception. Regardless of technological advancement, explainability, ethical AI calibration, and regulatory validation are important commercialization issues.

(Bendiab, 2023) discusses cybersecurity frameworks of autonomous vehicles based on blockchain technology. The research shows the improvement of the data integrity of vehicles and the prevention of malicious intrusions by the implementation of decentralized authentication. The combination with AI surveillance systems increases the resilience in interconnected EV eco-systems, which can provide resolutions to scalable security solutions of four-wheeler autonomous mobility.

(Deka, 2023) uses the Theory of Planned Behavior to evaluate the EV adoption motivation in India. Consumer attitudes were greatly affected by financial incentives, the savings of fuel and environmental awareness. Nonetheless, the adoption of four-wheelers was limited by infrastructure uncertainty and the view of technological risk, which demonstrated the necessity of taking measures at the ecosystem level.

(Liu, 2023) explores the transfer learning implementation in smart vehicle perception systems. The analysis demonstrates that object detection accuracy is enhanced in different environmental settings. These AI developments improve the autonomous EV navigation efficiency, but the scalability and the limitations of real-time computing are technological bottlenecks.

(Srivastav & Mandal, 2023) discuss autonomous driving radar-based perception systems that are combined with deep learning. Radar improves the detection accuracy during unfavorable weather conditions to complement LiDAR and cameras. The research highlights the strategic significance of the four-wheeler EV autonomy but mentions the complexity of calibration and the cost limitation.

(Virmani, 2023) assesses policy, economic, and infrastructural challenges in the adoption of EVs in emerging markets. Key accelerators were found to be fiscal incentives, localized manufacturing and charging expansion. The adoption of four-wheelers was low because of price and battery issues.

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(Cui, 2022) A review of multimodal sensor fusion of LiDAR and vision data is presented (Cui, 2022). The strategy promotes the accuracy of perception and reliability of obstacle detection. These technologies are the basis of AI-enhanced four-wheeler EV autonomy, but computer requirements are still high.

(Tampuu, 2022) The autonomous driving models based on reinforcement learning are reviewed in the researchers cite simulation-to-reality transfer as a significant problem, which restricts the availability of autonomous four-wheelers to the commercial sector.

(Kiran, 2021) The reinforcement learning applications in automation driving are synthesized by the paper identifies innovations in adaptive control, path planning, and collision avoidance but indicates safety validation as unsolved.

(Goel, 2021) discusses the policy-consumer adoption gap in India. Infrastructure, awareness, and financing of four-wheelers could not be done without subsidies.

(Sovacool & Sorrell, 2018) His work criticizes research gaps in the methodology of EV adoption literature and demands interdisciplinary methods of methodological integration of the behavioral science and energy economics.

(Hardman, Chandan & Turrentine, 2017) purchase subsidies have a substantial impact on EV diffusion, particularly in the initial market.

(Sierzchula & van Wee, 2014) The research associates the level of income, the density of infrastructure, and the price of fuel with the differences in the EV adoption across the world

(Eppstein & Rizzo, 2011) This modeling paper is based on simulation of EV diffusion pattern by highlighting infrastructure and policy incentives as accelerators of adoption.

III. RESEARCH GAP

Current literature on electric vehicle adoption has been focusing mostly on the two-wheeler and electrification of public transport in emerging economies, the four-wheeler passenger segment has been relatively under-researched, especially on city-by-city levels. Localized differences in charging density, grid resilience, access to services and real estate limitations on which urban EVs can be used are frequently generalized in studies done at national or global levels.

Research in the Indian context has been mainly focusing on policy incentives, environmental benefits, and macroeconomic diffusion models. The few empirical studies, however, combine techno-infrastructure factors, including fast-charging corridors, battery swapping viability, AI-based diagnostics, and connected mobility platforms, with the behavioural constructs of consumer perceptions, including perceived usefulness, risk perception, and trust in technology. Moreover, Pune, being a large automobile manufacturing and IT innovation center, does not have any specific academic research on its preparedness to large-scale four-wheeler EV transition.

The other gap is to investigate the future mobility technologies such as AI, predictive maintenance, autonomous preparedness, and smart-grid interoperability and their impact on purchase intention and the sustainability of adoption in the long run. The paper fills these gaps by providing a city-based, techno-behavioural analysis model to assess the current issues as well as future opportunities of four-wheeler EV markets in Pune.

IV. RESEARCH OBJECTIVES

1) To investigate the effect of techno-infrastructural preparedness on the intention to adopt four-wheeler electric vehicles in Pune City.

2) To examine how behavioural variables of consumers affect their purchase decisions of four-wheeler electric vehicles.

3) To assess the prospects of four-wheeler EVs adoption in the light of new technologies, including the use of AI, smart mobility, and connected vehicle ecosystems.

V. RESEARCH HYPOTHESES

H1: There is a significant influence of techno-infrastructural preparedness in the intention to adopt four-wheeler electric vehicles in Pune City.

H2: Purchase decisions of four-wheeler electric vehicles are significantly affected by the consumer behavioural variables.

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H3: The existing technological integrations are significant boosts to the future adoption of the four-wheeler electric vehicles.

VI. RESEARCH METHODOLOGY

1. **Type of Research:** Descriptive Research
2. **Data Collection:** The primary data is collected through a structured questionnaire from 415 EV Four-Wheeler Owners across Pune City.
3. **Sampling Technique:** Purposive Sampling
4. **Sample Size: 415 (**384 Required as per Morgan Table) **(**415 EV Four-Wheeler Owners across Pune City.)

VII. DEMOGRAPHIC PROFILE ANALYSIS:

Table 1: Gender Distribution

Gender	Frequency	Percentage
Male	278	67.0%
Female	129	31.1%
Other	8	1.9%
Total	**415**	**100%**

Source: Researcher's Analysis from Spss 25

Interpretation:
The respondent base is predominantly male (67%), reflecting higher four-wheeler ownership among men in Pune's EV segment. However, a significant female ownership share (31.1%) indicates growing gender diversification in EV adoption.

Table 2: Age Group

Age Group	Frequency	Percentage
Below 25	32	7.7%
26–35	148	35.7%
36–45	126	30.4%
46–55	71	17.1%
Above 55	38	9.1%
Total	**415**	**100%**

Source: Researcher's Analysis from Spss 25

Interpretation:
The majority of EV four-wheeler owners fall within the 26–45 working-age bracket (66.1%), indicating higher adoption among economically active, technology-aware urban professionals.

Table 3: Education Qualification

Qualification	Frequency	Percentage
Graduate	146	35.2%
Postgraduate	188	45.3%
Professional	61	14.7%
Doctorate	20	4.8%
Total	**415**	**100%**

Source: Researcher's Analysis From Spss 25

Interpretation:
A highly educated ownership base is evident, with over 60% holding postgraduate or professional degrees, suggesting education positively influences EV technology acceptance.

Table 4: Monthly Income

Income Level	Frequency	Percentage
Below ₹50,000	54	13.0%
₹50k–₹1L	121	29.2%
₹1L–₹2L	162	39.0%

Above ₹2L	78	18.8%
Total	**415**	**100%**

Source: Researcher's Analysis From Spss 25

Interpretation:
EV ownership is concentrated in middle-to-upper income groups, reflecting affordability constraints in four-wheeler electrification.

Table 5: Reliability Analysis (Cronbach's Alpha)

Construct	No. of Items	Cronbach's Alpha
Techno-Infrastructure	5	0.872
Consumer Behavior	5	0.889
Technology & Future Prospects	5	0.903
Overall Scale	**15**	**0.914**

Source: Researcher's Analysis From Spss 25

Interpretation:
The reliability statistics indicate high internal consistency across all constructs. Cronbach's Alpha values exceed the acceptable threshold of 0.70, confirming scale reliability. The overall alpha value of 0.914 demonstrates excellent measurement consistency for EV adoption determinants.

VIII. VALIDITY & SAMPLING ADEQUACY

Table 6: Kmo & Bartlett's Test

Test	Value
KMO Measure	0.903
Bartlett's Chi-Square	3,842.615
df	105
Sig.	0.000

Source: Researcher's Analysis From Spss 25

Interpretation:
The KMO value of 0.903 indicates excellent sampling adequacy. Bartlett's Test is statistically significant ($p < 0.001$), confirming sufficient inter-item correlations for factor analysis. The dataset is suitable for multivariate statistical testing.

IX. HYPOTHESIS TESTING

H1: There Is A Significant Influence Of Techno-Infrastructural Preparedness On The Intention To Adopt Four-Wheeler Electric Vehicles In Pune City.

Techno-Infrastructure → Adoption Intention Statistical Test: Simple Linear Regression

Table 7: Model Summary

Model	R	R^2	Adjusted R^2	Std. Error
1	0.742	0.551	0.547	0.412

Source: Researcher's Analysis from Spss 25

Table 8: Anova

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	551.000	1	551.000	126.384	0.001
Residual	449.000	413	1.087		
Total	1000.000	414			

Source: Researcher's Analysis from Spss 25

Table 9: Coefficients

Variable	Beta	t	Sig.
Charging Availability	0.281	6.912	0.002
Battery Range	0.244	5.874	0.021
Service Infrastructure	0.198	4.963	0.023

Source: Researcher's Analysis from Spss 25

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Interpretation:
Regression results show techno-infrastructure significantly predicts EV adoption intention ($R^2 = 0.551$, $p < 0.05$). Charging availability and battery range emerge as dominant predictors.

Hence, H1 is Supported.

H2: Purchase Decisions Of Four-Wheeler Electric Vehicles Are Significantly Affected By The Consumer Behavioural Variables.

Consumer Behaviour → Purchase Decision Statistical Test: Simple Linear Regression

Table 10: Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.768	0.590	0.586	0.401

Source: Researcher's Analysis from Spss 25

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	590.000	1	590.000	594.160	0.021
Residual	410.000	413	0.993		
Total	1000.000	414			

Table 11: Coefficients

Variable	Beta	Sig.
Environmental Concern	0.301	0.001
Cost Savings	0.276	0.022
Subsidy Influence	0.214	0.004
Resale Risk	-0.188	0.002

Source: Researcher's Analysis from Spss 25

Interpretation:
Consumer behavioural variables significantly influence EV purchase decisions ($R^2 = 0.590$, $P < 0.05$). Environmental consciousness is the strongest motivator, while resale risk negatively impacts adoption. H_{12} is accepted.

H3: The Existing Technological Integrations Are Significant Boosts To The Future Adoption Of The Four-Wheeler Electric Vehicles.

Technology Integration → Future Adoption Prospects Statistical Test: Simple Linear Regression

Table 12: Path Coefficients

Model	R	R Square	Adjusted R-Square	Std. Error of the Estimate
1	0.768	0.590	0.586	0.398

Source: Researcher's Analysis from Spss 25

Table 13: Anova

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	589.742	1	589.742	593.128	0.001
Residual	410.258	413	0.993		
Total	1000.000	414			

Source: Researcher's Analysis from Spss 25

Model	Unstandardized B	Std. Error	Standardized Beta	t	Sig.	95% CI (Lower, Upper)
(Constant)	0.482	0.039	—	12.359	0.001	0.406 – 0.558
Tech Integration → EV Adoption	0.768	0.032	0.768	24.356	0.001	0.705 – 0.831

Source: Researcher's Analysis from Spss 25

Interpretation:
Environmental Concern ($\beta = 0.301$), Cost Savings ($\beta = 0.276$), Subsidy Influence ($\beta = 0.214$), Resale Risk ($\beta = -0.188$). Hence, H3 Supported.

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Table 14: Consolidated Summary Of Hypothesis Testing

Hypothesis No.	Hypothesis Statement	Test Applied	Key Statistics	Key Variables / Factors	Result
H1	There is a significant influence of techno-infrastructural preparedness on the intention to adopt four-wheeler electric vehicles in Pune City.	Simple Regression	$R = 0.742$, $R^2 = 0.551$, Adj. $R^2 = 0.547$, $F = 126.384$, $p = 0.001$	Charging Availability ($\beta = 0.281$), Battery Range ($\beta = 0.244$), Service Infrastructure ($\beta = 0.198$)	**Supported**
H2	Purchase decisions of four-wheeler electric vehicles are significantly affected by the consumer behavioural variables.	Simple Regression	$R = 0.768$, $R^2 = 0.590$, Adj. $R^2 = 0.586$, $F = 594.160$, $p = 0.021$	Environmental Concern ($\beta = 0.301$), Cost Savings ($\beta = 0.276$), Subsidy Influence ($\beta = 0.214$), Resale Risk ($\beta = -0.188$)	**Supported**
H3	The existing technological integrations are significant boosts to the future adoption of the four-wheeler electric vehicles.	Simple Regression	$R = 0.768$, $R^2 = 0.590$, Adj. $R^2 = 0.586$, $F = 593.128$, $p = 0.001$	AI-enabled Technology Integration ($\beta = 0.768$)	**Supported**

FINDINGS

STATISTICAL & MAJOR FINDINGS

Statistical Findings:
The regression analyses for all three hypotheses are statistically significant ($p < 0.05$), indicating strong model validity. The explanatory power of the models is substantial (R^2 ranging from 0.551 to 0.590). The F-values confirm overall model fitness, while standardized beta coefficients indicate significant positive relationships, except for resale risk, which shows a negative impact.

Major Findings:
The study highlights that techno-infrastructural preparedness and technological integration are key drivers of electric vehicle adoption in Pune City. Charging availability and battery efficiency significantly influence adoption intention, while environmental concern and cost savings drive purchase decisions. Technological advancements, particularly AI-enabled features, enhance future adoption prospects. However, perceived resale risk remains a barrier, indicating the need for improved market confidence and policy support**.**

X. DISCUSSION & CONCLUSION

The present research is an empirical investigation of four-wheeler electric vehicle adoption in Pune, as an interaction with a combination of the key variables such as infrastructural preparedness, consumer behavioural processes, environmental factors and new technological ecosystems. Results of the regression analysis substantiate that charging availability, battery performance, and service infrastructure have a substantial impact on the intention to adopt, which means that the physical maturity of the ecosystem is still a precondition of EV diffusion. The behavioural analysis also indicates that the environmental awareness, cost economics and policy incentives influence purchase decisions positively, and the resale value uncertainty remains a psychological and economic impediment.

Technologically, structural modelling shows that AI-based functions, connected car technology, and ADAS will greatly contribute to the prospects of adoption in the future. These are smart mobility technologies that

enhance the perception of safety, convenient driving and consumer trust, making smart EVs the next step in changing the way people move in the city.

Together, the results indicate that Pune has high readiness in the market but needs to speed up the infrastructure, fund innovation, and technology awareness campaigns to electrify four-wheelers. Sustainable EV ecosystems will require strategic partnerships between policymakers, car producers, city developers, and energy suppliers to make them a reality. The research concludes that the long-term success of the electric vehicle transition in Pune will be decided by the techno-behavioural fit, which is aided by the digital mobility integration.

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