Cost, Performance, and Sustainability Comparison between ICE Vehicles, Electric Vehicles and Alternate Fuel Vehicles and Their Impact on Adoption Intention

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ABSTRACT

The global automotive industry is undergoing a significant transformation driven by environmental concerns, rising fuel costs, and technological advancements. This study presents a focused comparative analysis of Internal Combustion Engine (ICE) vehicles, Electric Vehicles (EVs), and Alternate Fuel Vehicles (AFVs) across two primary objectives: (1) to compare these vehicle types in terms of cost, performance, and sustainability, and (2) to analyse how these factors influence user satisfaction, which in turn affects adoption intention. A quantitative descriptive research approach was adopted, with primary data collected from 255 respondents through a structured Likert-scale questionnaire. Statistical tools including One-Way ANOVA (Welch's), Tukey post-hoc tests, multiple regression analysis, and mediation analysis were applied using JAMOVI 2.3.28. The instrument reliability was confirmed through a Cronbach's Alpha of 0.814. Results indicate that while cost and performance perceptions do not differ significantly across vehicle types, sustainability perceptions are significantly higher among EV and AFV owners. Regression analysis reveals that performance is the strongest driver of user satisfaction ($\beta = 0.438$), followed by cost ($\beta = 0.391$) and sustainability ($\beta = 0.304$). Mediation analysis confirms that user satisfaction partially mediates the relationship between each factor and adoption intention. The findings provide actionable insights for consumers, manufacturers, and policymakers navigating the transition to sustainable transportation.

Keywords: Automotive sector, Internal Combustion Engine (ICE) vehicles, Electric Vehicles (EVs), and Alternate Fuel Vehicles (AFVs), cost, performance, and sustainability, comparative analysis, transportation, environmental concerns, rising fuel costs, technological advancements.

INTRODUCTION

The global automobile sector is presently undergoing a significant transformation as issues related to fuel security, environmental sustainability, and technological advancements redefine the future of transportation. For many years, Internal Combustion Engine (ICE) vehicles have been the predominant force in the mobility sector, owing to their well-established infrastructure, cost-effectiveness, and reliable performance. Nevertheless, escalating fuel costs, rising greenhouse gas emissions, and more stringent government regulations aimed at minimizing carbon footprints have hastened the quest for cleaner and more sustainable alternatives. Consequently, Electric Vehicles (EVs) and Alternate Fuel Vehicles (AFVs), including those powered by Compressed Natural Gas (CNG), biofuels, and hydrogen, are receiving considerable attention on a global scale.

ICE vehicles predominantly run on petrol or diesel and are characterized by impressive driving range, rapid refuelling capabilities, and a broad service network. However, they significantly contribute to air pollution and carbon emissions. In contrast, EVs utilize electric motors powered by rechargeable batteries and are acknowledged for zero tailpipe emissions and reduced operational costs, though obstacles such as higher initial purchase price, charging infrastructure limitations, and range anxiety continue to affect adoption. AFVs offer a

middle ground by employing cleaner fuels to minimize emissions while maintaining performance standards comparable to traditional vehicles.

This research study focuses specifically on two primary objectives: (1) to compare ICE vehicles, EVs, and AFVs in terms of cost, performance, and sustainability; and (2) to analyse how these factors influence user satisfaction and, subsequently, adoption intention. The importance of this research resides in its endeavour to deliver a thorough assessment that amalgamates economic, technical, and environmental viewpoints for the benefit of consumers, policymakers, and automobile manufacturers.

Statement of the problem

The automotive sector is experiencing a significant transformation driven by escalating environmental issues, surging fuel costs, technological innovations, and more stringent emission standards. Although ICE vehicles have historically led the market owing to their cost-effectiveness, established infrastructure, and dependable performance, growing environmental consciousness has spurred the development and advocacy of EVs and AFVs. Nevertheless, substantial uncertainty persists among consumers and stakeholders concerning the relative merits and drawbacks of these vehicle categories.

While EVs and AFVs are frequently marketed as eco-friendly options, doubts remain regarding their overall cost-effectiveness, performance efficiency, and long-term sustainability compared to traditional ICE vehicles. Existing research frequently emphasises singular elements such as environmental advantages or financial savings; however, there is a notable deficiency in integrated analyses that concurrently assess cost, performance, and sustainability across all three vehicle categories. Furthermore, the linkage between these factors, user satisfaction, and adoption intention remains inadequately examined.

Consequently, this study addresses the lack of a thorough and comparative assessment of ICE vehicles, EVs, and AFVs concerning cost, performance, and sustainability criteria, and further examines how these dimensions mediate the pathway from consumer perceptions to adoption behaviour through user satisfaction.

The main objectives of the study are as follows:

- To compare ICE Vehicles, Electric Vehicles (EVs), and Alternate Fuel Vehicles in terms of cost, performance, and sustainability.

- To analyse how cost, performance, and sustainability factors influence user satisfaction and adoption intention with ICE Vehicles, EVs, and Alternate Fuel Vehicles.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Brief Theoretical Construct Related to the Problem

The theoretical framework of this study integrates four key constructs drawn from prior literature. The Technology Acceptance Model (TAM), Davis (1989) provides a foundational basis, proposing that perceived usefulness and perceived ease of use are the primary determinants of technology adoption intention. In the vehicle context, perceived performance (usefulness) and cost-efficiency (ease of practical adoption) align with TAM's core constructs. This study extends TAM by incorporating sustainability as an additional determinant of satisfaction.

The Total Cost of Ownership (TCO) framework evaluates vehicles beyond initial purchase price, encompassing fuel or energy costs, maintenance, depreciation, insurance, and resale value—enabling a holistic economic comparison across vehicle types. The Lifecycle Assessment (LCA) framework underpins the sustainability dimension, evaluating each vehicle type's ecological footprint across its entire lifespan, including indirect emissions from electricity generation and battery production. Finally, Oliver's (1980) Expectation-Confirmation Theory explains user satisfaction as the result of consumers' evaluation of product performance against prior

expectations, with satisfaction subsequently driving adoption intention. This mediating role of satisfaction is a central theoretical proposition of this research.

An Overview of Earlier Studies

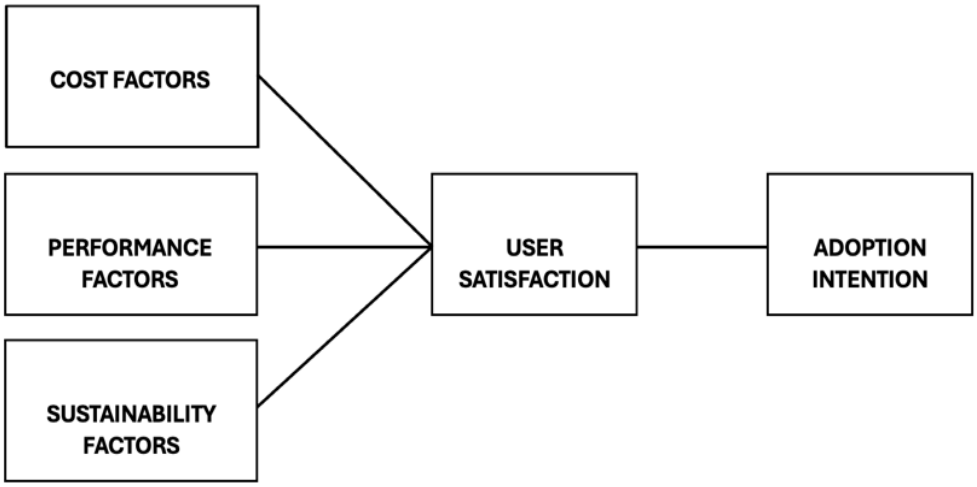
The global automotive sector has been extensively examined in both academic and policy research over the last twenty years, particularly concerning environmental sustainability, energy security, technological advancements, and economic viability. Cost-based comparative studies, such as Ayodele and Mustapa (2020), demonstrate that while EVs require higher initial investment, they offer lower running and maintenance costs over time, with total cost of ownership becoming competitive within five to eight years. Research on AFVs suggests that CNG vehicles present moderate acquisition costs and reduced fuel expenses, though refuelling infrastructure remains a critical determinant of economic viability.

Performance-oriented research historically lauded ICE vehicles for their driving range and refuelling convenience. However, the Energy Journal (2023) showed that EVs recover up to 15–20% of their total energy through regenerative braking under urban driving cycles—an efficiency advantage unavailable in ICE vehicles. Studies by Singh et. al (2025) confirmed that EVs perform most efficiently in urban stop-and-go traffic, while ICE vehicles remain more suitable for long-distance rural travel.

Sustainability studies consistently identify ICE vehicles as major contributors to greenhouse gas emissions. Investigations into EVs underscore zero tailpipe emissions, though scholars note that EV sustainability depends significantly on the electricity generation mix. Dolganova (2024) highlighted that improving battery recycling systems is necessary for long-term EV sustainability. Studies on consumer behaviour indicate that environmental consciousness, perceived financial benefits, and social influence drive adoption intention. The Powertrain Alliance (2025) found that countries with comprehensive policy support have achieved EV market shares exceeding 25%.

While many studies examine cost, performance, or sustainability in isolation, there are comparatively fewer that take an integrated approach simultaneously assessing all three dimensions across ICE, EV, and AFV technologies. This integrated gap, along with the mediating role of user satisfaction in translating these perceptions into adoption intention in the Indian context, forms the foundation of this research.

Fig 1: Research Model



Independent Variables: Cost Factors, Performance Factors, Sustainability Factors

Mediating Variable: User Satisfaction

Dependent Variable: Adoption Intention

METHODOLOGY

The present study employs a quantitative, descriptive research approach to examine consumer perceptions of cost, performance, and sustainability across ICE vehicles, EVs, and AFVs, and to assess how these factors influence user satisfaction and adoption intention. Primary data was collected through a structured questionnaire distributed to vehicle users and prospective purchasers. The questionnaire comprised statements evaluated on a five-point Likert scale (Strongly Disagree to Strongly Agree), capturing attitudes toward vehicle affordability, maintenance costs, fuel efficiency, driving performance, environmental consequences, and long-term sustainability.

Convenience sampling was employed, with a final sample of 255 respondents. This sample size was deemed sufficient for statistical analysis while ensuring practical feasibility. Reliability was confirmed through Cronbach's Alpha of 0.814, indicating good internal consistency. Content validity was ensured by grounding all questionnaire items in existing literature. Data was analysed using JAMOVI 2.3.28 through descriptive statistics, One-Way ANOVA (Welch's), Tukey post-hoc tests, multiple regression analysis, and mediation analysis.

RESULTS

The collected data was analysed using JAMOVI 2.3.28 . Descriptive statistics summarise the characteristics of the sample and variables. Inferential statistics—ANOVA, regression, and mediation analysis—were used to examine relationships between variables and test objectives.

Demographic Profile

Table 1: Age Group Classification

Age Group	Count	% of Total	Cumulative %
Below 25	55	21.6%	21.6%
26–35	38	14.96%	36.56%
36–45	25	9.84%	46.40%
46–55	72	28.35%	74.75%
Above 55	64	25.20%	100%

Source: Primary Data

The largest segment comprises respondents aged 46–55 years (28.35%), followed by those above 55 years (25.20%). Together, respondents over 45 account for more than half the sample (54%).

Table 2: Gender Distribution

Gender	Count	% of Total	Cumulative %
Female	115	45.1%	45.1%
Male	140	54.9%	100%

Source: Primary Data

The sample comprises 140 male (54.9%) and 115 female (45.1%) respondents, providing a relatively balanced gender distribution.

Reliability Analysis

Table 3: Scale Reliability Statistics

Scale	Cronbach's α
Overall Scale	0.814

Source: JAMOVI Output

A Cronbach's Alpha of 0.814 confirms good internal consistency, indicating that the questionnaire items consistently measure the intended constructs and the instrument is appropriate for further statistical analysis.

Objective 1: Comparison of Vehicle Types across Cost, Performance, and Sustainability

Objective 1 examines whether significant differences exist among ICE vehicle, EV, and AFV owners in their perceptions of cost, performance, and sustainability. One-Way ANOVA (Welch's) was applied with vehicle type as the independent variable.

Table 4: Group Descriptives of Major Variables

Variable	Vehicle Type	N	Mean	SD	SE
Cost Factors Index	Alternate Fuels (CNG, LPG, Hydrogen)	76	3.92	0.539	0.0618
	Electric Vehicle (EV)	72	4.03	0.495	0.0583
	ICE Vehicle	107	4.08	0.563	0.0545
Performance Factors Index	Alternate Fuels (CNG, LPG, Hydrogen)	76	4.03	0.431	0.0495
	Electric Vehicle (EV)	72	3.91	0.608	0.0717
	ICE Vehicle	107	4.08	0.441	0.0426
Sustainability Factors Index	Alternate Fuels (CNG, LPG, Hydrogen)	76	3.98	0.611	0.0701
	Electric Vehicle (EV)	72	4.01	0.505	0.0595
	ICE Vehicle	107	3.79	0.615	0.0595

Source: JAMOVI Output

For Cost, ICE vehicle owners report the highest mean (4.08), followed by EV owners (4.03) and AFV owners (3.92). For Performance, ICE owners again report the highest mean (4.08). For Sustainability, EV owners (4.01) and AFV owners (3.98) score higher than ICE owners (3.79), highlighting that environmentally friendly vehicle users place greater importance on sustainability.

Table 5: One-Way ANOVA (Welch's) Results

Variable	F	df1	df2	p-value	Significant?
Cost Factors Index	1.79	2	160	0.171	No
Performance Factors Index	2.13	2	149	0.122	No
Sustainability Factors Index	3.96	2	161	0.021	Yes

Source: JAMOVI Output

No statistically significant differences are found for Cost (p = 0.171) and Performance (p = 0.122), indicating similar perceptions across all groups. However, Sustainability shows a statistically significant difference (p = 0.021 < 0.05), indicating meaningful variation across vehicle types.

Table 6: Levene's Homogeneity of Variances Test

Variable	**F**	**df1**	**df2**	**p-value**
Cost Factors Index	1.87	2	252	0.157
Performance Factors Index	4.89	2	252	0.008
Sustainability Factors Index	2.26	2	252	0.107

Source: JAMOVI Output

Levene's test confirms equal variances for Cost (p = 0.157) and Sustainability (p = 0.107). For Performance (p = 0.008), the equal variance assumption is violated; hence Welch's ANOVA was appropriately applied.

Table 7: Tukey Post-Hoc Test – Sustainability Factors Index

Comparison	**Mean Difference**	**p-value**	**Significant?**
AFV vs EV	-0.0314	0.943	No
AFV vs ICE	0.191	0.077	No
EV vs ICE	0.223	0.035	Yes

Source: JAMOVI Output

For Cost and Performance, no pairwise comparisons are statistically significant (all p > 0.05). For Sustainability, a significant difference is found between EV owners and ICE vehicle owners (p = 0.035 < 0.05), with EV owners exhibiting significantly higher sustainability perceptions—confirming the ANOVA result is driven primarily by the EV-vs-ICE contrast.

Objective 2: Effect of Cost, Performance, and Sustainability on User Satisfaction and Adoption Intention

Objective 2 examines how cost, performance, and sustainability factors influence user satisfaction (Model 1), and how user satisfaction influences adoption intention (Model 2). Mediation analysis then tests whether satisfaction mediates each of the three IV-to-adoption pathways.

Model 1: DV = User Satisfaction Index; IVs = Cost Index, Performance Index, Sustainability Index

Model 2: DV = Adoption Intention Index; IV = User Satisfaction Index

Table 8: Model 1 Fit Measures – Predicting User Satisfaction

Model	**R**	**R^2**	**F**	**df1**	**df2**	**p**
1	0.491	0.241	26.6	3	251	<.001

Note. Models estimated using sample size of N = 255

The model is statistically significant ($F(3, 251) = 26.6$, $p < .001$). Cost, performance, and sustainability collectively explain 24.1% of the variance in user satisfaction ($R^2 = 0.241$).

Table 9: Model 1 Coefficients – Predicting User Satisfaction

Predictor	**Estimate (β)**	**SE**	**t**	**p**
Intercept	1.046	0.2254	4.64	<.001
Cost Factors Index	0.391	0.0587	6.66	<.001
Performance Factors Index	0.438	0.0637	6.89	<.001
Sustainability Factors Index	0.304	0.0547	5.55	<.001

Source: JAMOVI Output

All three predictors are statistically significant. Performance Factors ($\beta = 0.438$, $t = 6.89$) has the strongest influence on user satisfaction, followed by Cost Factors ($\beta = 0.391$) and Sustainability Factors ($\beta = 0.304$).

Table 10: Model 2 Fit Measures – Predicting Adoption Intention

Model	**R**	**R^2**	**F**	**df1**	**df2**	**p**
2	0.438	0.192	59.9	1	253	<.001

Note. Models estimated using sample size of N = 255

User satisfaction significantly predicts adoption intention ($F(1, 253) = 59.9$, $p < .001$), explaining 19.2% of the variance in adoption intention ($R^2 = 0.192$).

Table 11: Model 2 Coefficients – Predicting Adoption Intention

Predictor	**Estimate (β)**	**SE**	**t**	**p**
Intercept	2.538	0.1988	12.77	<.001
User Satisfaction Index	0.381	0.0492	7.74	<.001

Source: JAMOVI Output

For every one-unit increase in user satisfaction, adoption intention increases by 0.381 units ($p < .001$), confirming satisfaction as a significant predictor and mediating variable.

Mediation Analysis

Table 12: Mediation Summary – All Three Pathways

Pathway	**Indirect Effect**	**Direct Effect**	**Total Effect**	**Mediation Type**
Cost → Satisfaction → Adoption	0.105 (p<.001)	0.297 (p<.001)	0.401 (p<.001)	Partial
Performance → Satisfaction → Adoption	0.100 (p<.001)	0.426 (p<.001)	0.526 (p<.001)	Partial
Sustainability → Satisfaction → Adoption	0.082 (p<.001)	0.316 (p<.001)	0.398 (p<.001)	Partial

Source: JAMOVI Mediation Analysis Output

Mediation analyses confirm partial mediation across all three models. Indirect effects are positive and statistically significant (Cost: 0.105; Performance: 0.100; Sustainability: 0.082; all $p < .001$), confirming that user satisfaction meaningfully transmits the effect of these factors on adoption intention. The direct effects also remain strong and significant, indicating that each factor independently influences adoption. Performance exhibits the largest total effect (0.526), confirming its dominant role in shaping adoption behaviour.

DISCUSSION

The results present a nuanced picture of consumer perceptions across vehicle types. The absence of significant differences in cost and performance perceptions is noteworthy: despite objective structural differences in the cost and performance profiles of ICE, EV, and AFV technologies, users across all groups perceive these dimensions comparably. This convergence may reflect growing consumer awareness of EV lifecycle cost advantages, or indicate that AFV and ICE users have normalised their higher fuel costs within their evaluation framework.

The significant difference in sustainability perceptions—particularly between EV and ICE owners—aligns with prior literature indicating that environmentally conscious consumers self-select into greener vehicle categories. The practical implication is that sustainability messaging is most effective with already-converted audiences, and different communication strategies are needed to shift ICE users toward environmental consideration.

The mediation results provide strong empirical support for the proposed theoretical framework. The finding that satisfaction partially mediates all three pathways indicates that enhancing user experience is as important as improving technical specifications. Performance emerges as the most powerful driver of satisfaction and adoption, suggesting that manufacturers should prioritise perceived driving quality, reliability, and efficiency as core value propositions. The dual pathway—direct and mediated—indicates that both rational evaluation and experiential satisfaction shape vehicle adoption simultaneously.

For consumers, findings suggest that long-term total cost of ownership, particularly for EVs, offers significant economic advantages. For manufacturers, performance enhancements and effective communication are the most critical levers for increasing satisfaction and adoption. For policymakers, targeted awareness campaigns should be directed at ICE vehicle users to shift environmental attitudes before purchase decisions are made. For marketers, since cost perceptions do not differ significantly across groups, campaigns should focus on experiential dimensions—driving comfort, reliability, and overall ownership experience—that most directly influence satisfaction and adoption intention.

Scope for future research

Future research should utilise stratified random sampling with larger and geographically diverse samples to enhance generalisability. The model could be extended to incorporate additional mediating variables such as brand trust, infrastructure availability perception, and social influence. Longitudinal studies tracking how consumer perceptions evolve over time—particularly as EV infrastructure expands and battery technology improves—would provide dynamic insights into shifting adoption trajectories. Comparative studies across different countries and regulatory environments would help isolate the effect of policy interventions on the cost-performance-sustainability perception matrix. Qualitative methods such as interviews and focus groups could complement quantitative findings by providing richer contextual understanding of the sustainability perception gap between EV and ICE vehicle users.

CONCLUSION

This study has presented a focused comparative analysis of ICE vehicles, EVs, and AFVs through quantitative research. The key finding is that while cost and performance perceptions do not differ significantly across vehicle groups, sustainability perceptions are significantly higher among EV and AFV owners compared to ICE owners—driven primarily by the EV-vs-ICE contrast. This suggests that the sustainability narrative has successfully penetrated the EV user base but has not yet shifted attitudes among conventional ICE vehicle users. The study also confirms that performance is the strongest driver of user satisfaction ($\beta = 0.438$), followed by

cost (β = 0.391) and sustainability (β = 0.304). Together, these three factors explain 24.1% of the variance in satisfaction. User satisfaction, in turn, significantly predicts adoption intention, and mediation analysis confirms a consistent partial mediation effect across all three pathways. For the transition to sustainable mobility to accelerate, the consumer experience must also be elevated, as it is the bridge between product attributes and adoption behaviour. These empirically grounded findings offer a valuable compass for manufacturers, policymakers, and marketers shaping the future of sustainable transportation.

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