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Factors Driving Electric Three Wheeler Adoption in India using an Integrated Behavioral Framework

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Running title: Electric Three-Wheeler Adoption in India

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Abstract

Background and Objective:

The urban mobility revolution in India has entered a new phase with the rapid electrification of three-wheelers (3W). India currently represents the world's largest electric three-wheeler (E3W) market, recording over 6 lakh registrations in 2024. This study investigates the multidimensional determinants influencing the adoption of electric three-wheelers in India's last-mile mobility market, encompassing both passenger (auto-rickshaws) and cargo applications

Materials and Methods:

The study utilized a mixed-source approach based on secondary literature, market reports, and primary survey data collected from 450 commercial operators, fleet managers, and policymakers across six Indian cities. A combined theoretical framework integrating the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Theory of Planned Behaviour (TPB) was employed. Multiple regression analysis was conducted to examine the determinants of E3W adoption.

Results:

The findings identified nine key drivers of adoption: government policies and financial incentives, economic benefits through lower total cost of ownership, charging infrastructure availability, battery swapping practicality, social influence and peer adoption, financing access, environmental concern, perceived range adequacy, and urban growth with rising last-mile demand. The regression model showed significant explanatory power ($R^2 = 0.581$, $F(9, 440) = 67.78$, $p < .001$), with charging infrastructure ($\beta^* = 0.329$) and economic benefit ($\beta^* = 0.289$) emerging as the strongest predictors. All nine direct-effect hypotheses (H1–H9) were supported.

Conclusion:

The study highlights the critical role of infrastructure development, financial viability, and supportive policy frameworks in accelerating electric three-wheeler adoption in India. The findings provide practical insights for policymakers and industry stakeholders to strengthen sustainable last-mile mobility systems while identifying directions for future research.

Keywords: *Electric three-wheelers, last-mile connectivity, EV adoption, India, UTAUT*

INTRODUCTION

The urban transport sector in India is confronted with several challenges: rapid urbanisation, degradation of air quality, rising prices of fossil fuels, and the so-called last-mile problem of transport and connecting transport hubs with the final destination. A new solution that has become critical is electric three-wheelers (E3Ws), which are used to transport passengers (auto-rickshaws) and cargo. With more than 6 lakh registrations in 2024 and a projected increase to 1.4 1.8 million annually by 2030, India has become the largest market in the world, in terms of E3Ws[1].

The market of the electric three-wheeler in India is estimated to grow at a CAGR of 13.40% to USD 4.08 billion by 2034 [2]. Although there has been a massive growth, academic literature on the drivers of E3W adoption in a commercial operator sense is limited. The three-wheeler commercial sector is under-studied in other research, even though the most common EV adoption studies concern four-wheeled passenger vehicles or two-wheelers [3].

EV adoption research draws on established technology-adoption and behavioural theories. The Technology Acceptance Model (TAM)[4] and its extension, the Unified Theory of Acceptance and Use of Technology (UTAUT)[5], together with the Theory of Planned Behaviour (TPB)[6], have each been applied to EV contexts: perceived economic benefit, especially fuel-cost savings, has emerged as a significant predictor of adoption intention in India[7],[8], social influence and peer norms have been shown to shape adoption decisions in Asian EV markets[9],[10], and subjective norms and perceived behavioural control have proven especially relevant for commercial three-wheeler drivers, where peer pressure and access to financing are strong predictors of switching behaviour[11],[12]. This study integrates UTAUT and TPB, supplemented with economic constructs,

to capture the utilitarian, social, and behavioural drivers relevant to commercial E3W operators specifically. This is a distinct segment: Goel et al.[3] found that E3W adoption in India substantially outpaces four-wheeler EV adoption, underscoring the segment's distinct adoption dynamics.

Empirically, four themes recur in the literature. First, government incentives are a consistent driver of adoption[13]; in India, the FAME-II scheme (INR 10,000 crore allocated to electric three-wheelers) and the 2024 Electric Mobility Promotion Scheme have expanded incentives for two- and three-wheelers, though incentives alone are insufficient where charging infrastructure and financing remain constrained[14]. Second, total cost of ownership is decisive for commercial operators: while upfront price is the single greatest adoption barrier[15], the lifetime cost of E3Ws is substantially lower than CNG or diesel alternatives, with switching operators reporting daily fuel savings of INR 200–500[16]. Third, advances in lithium-ion and LFP battery chemistry have improved range, but range anxiety, degradation, and charging time remain key barriers[17]; battery-swapping networks such as Sun Mobility and Battery Smart address this by reducing downtime to under five minutes[1]. Fourth, social and behavioural factors matter: direct experiential trials and peer-ambassador programmes have proven a cost-effective way to shift adoption intentions[18], and financing friction, rather than price alone, has been shown to be a stronger predictor of non-adoption[19].

Despite this growing body of work, three gaps remain. Most studies treat three-wheelers as a homogeneous segment, without distinguishing the organised L5M (auto-rickshaw) segment from the unorganised L3 (e-rickshaw) segment; comparative analysis across Indian states, despite wide variation in policy and infrastructure, remains limited; and the role of gender in E3W

adoption has received little attention. This study addresses the first two gaps through a stratified, multi-city sampling design, providing an empirical investigation of adoption drivers among 450 commercial E3W operators across six Indian cities using an integrated UTAUT+TPB framework.

The study is guided by one primary objective: to identify and rank the key factors that drive adoption of electric three-wheelers among commercial operators in India's last-mile connectivity sector.

To support this aim, the study pursues six secondary objectives:

1. To examine the influence of government policies and financial incentives (e.g., FAME-II subsidies, road tax waivers) on E3W adoption intention.
2. To assess the role of total cost of ownership — including fuel savings, maintenance costs, and upfront price — in shaping operators' switching decisions.
3. To evaluate the impact of charging infrastructure and battery swapping availability on adoption intentions.
4. To explore the effect of social influence — including peer adoption and community norms — on individual adoption decisions.
5. To investigate the moderating role of geographic context (city tier and region) on the relationship between adoption drivers and adoption intention.
6. To identify primary barriers inhibiting E3W adoption and propose evidence-based recommendations to address them.

These objectives translate into ten testable hypotheses, derived from the integrated UTAUT+TPB theoretical framework and domain-specific literature. Each hypothesis proposes a

relationship between an independent variable and E3W adoption intention (measured on a 5-point Likert scale), summarised in Table 1.

Table 1

Research Hypotheses and Theoretical Basis

H1	Government financial incentives (subsidies, tax waivers) have a significant positive effect on E3W adoption intention.	TPB; Zhang et al.[4]
H2	Perceived economic benefit (lower fuel and maintenance costs) has a significant positive effect on E3W adoption intention.	TAM; Jaiswal et al.[5]
H3	High upfront vehicle purchase price has a significant negative effect on E3W adoption intention.	Tarei et al.[6]
H4	Perceived adequacy of charging infrastructure has a significant positive effect on E3W adoption intention.	UTAUT; Kumar & Alok[17]
H5	Availability of battery-swapping facilities has a significant positive effect on E3W adoption intention.	UTAUT; Rathore et al.[7]
H6	Social influence (peer adoption and community norms) has a significant positive effect on E3W adoption intention.	UTAUT; Manutworakit & Choocharukul[8]
H7	Access to affordable financing (loans, EMI schemes) has a significant positive effect on E3W adoption intention.	TPB; Murugan & Marisamynathan[9]
H8	Environmental concern has a significant positive effect on E3W adoption intention.	TPB; Sahoo et al.[10]
H9	Perceived range adequacy of electric three-wheelers has a significant positive effect on E3W adoption intention.	TAM; Murugan & Marisamynathan[9]
H10	Geographic context (city tier and region) significantly moderates the relationship between adoption drivers and E3W adoption intention.	Contextual moderation; Bain[18]

Note. H1–H9 are tested as direct-effect propositions using multiple regression and SEM. H10 is tested as a moderation hypothesis using interaction terms and multi-group SEM.

METHODOLOGY

Research Design

The research design used in this study is quantitative and explanatory in nature, employing a cross-sectional survey design. The theoretical framework developed is an integrated UTAUT[5] and TPB[6] both are supplemented with economic variables (TCO, financing access) that have been identified in domain-specific literature. This integrated framework, showing the hypothesized relationships between each construct and adoption intention, is presented in Figure 1.

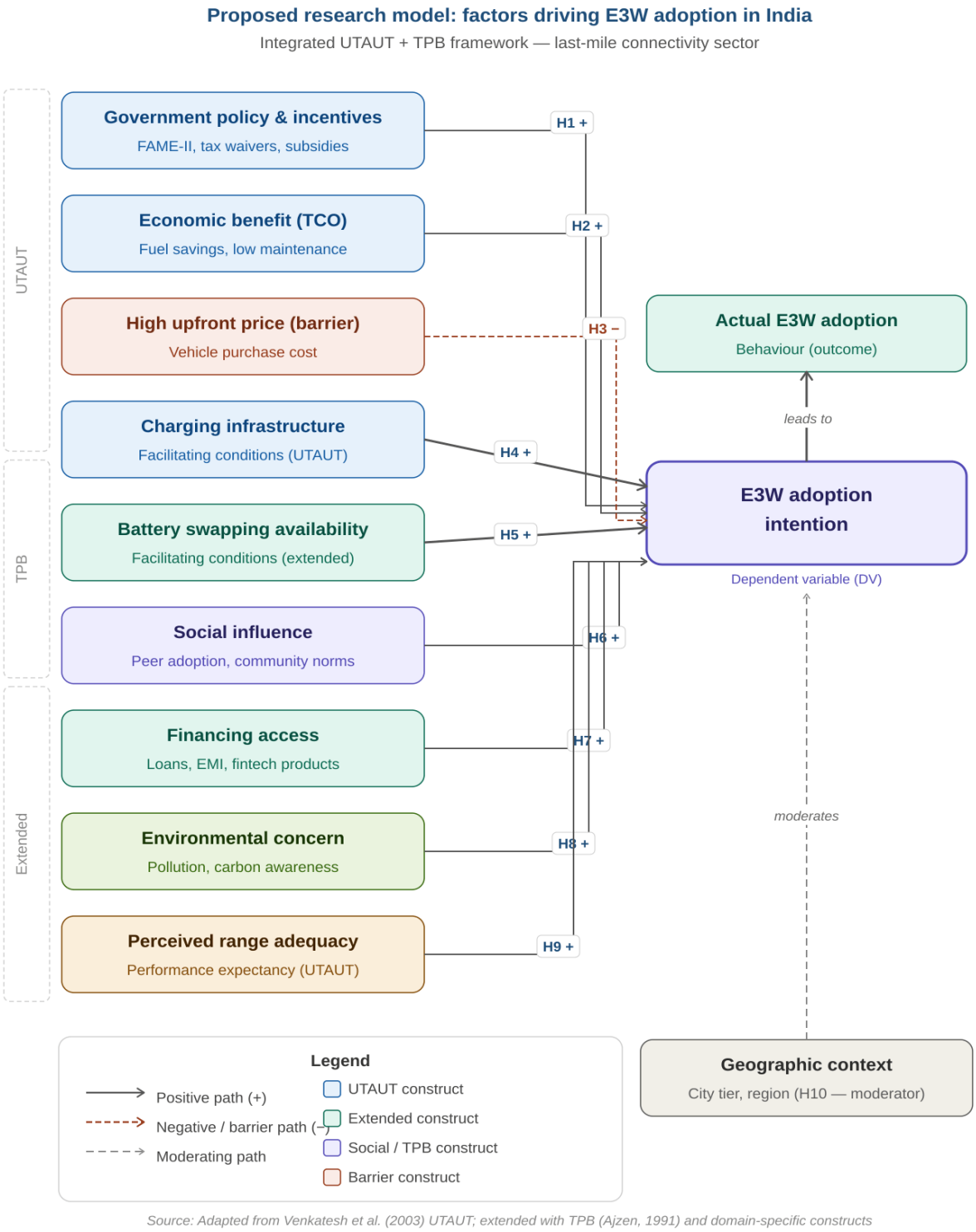


Figure 1: Proposed Research Model — Factors Driving E3W Adoption in India's Last-Mile Connectivity Sector

Source: Adapted from Venkatesh et al.[13] UTAUT; extended with TPB[15] and domain-specific constructs

Study Setting and Period

The study was conducted between January 2026 and March 2026 across six Indian cities selected for their high concentration of electric three-wheeler commercial activity: Delhi, Mumbai, Bengaluru, Lucknow, Coimbatore, and Patna, spanning North, West, South, and East India respectively.

Population

The target population comprised current and potential electric three-wheeler (E3W) operators in urban and peri-urban last-mile connectivity sectors across these six cities, including both passenger (auto-rickshaw) and cargo operators.

Sampling and Sample Size

The sampling was done using a stratified purposive approach, stratified by operator type (passenger vs. cargo), city, region (North, South, East, West India), and adoption status (current E3W user vs. ICE/CNG operator). The sample size was 450 respondents, distributed across the six cities as follows: Delhi (100), Mumbai (90), Bengaluru (80), Lucknow (80), Coimbatore (50), and Patna (50). Within this sample, operator type was evenly split between passenger and cargo operators (225 each), and adoption status was evenly split between current E3W users and ICE/CNG operators (225 each). This sample size gives statistical power >0.80 at the 5% level of significance in the planned regression and factor analysis. Respondents were identified and recruited through three-wheeler dealerships in each city: dealership operators provided the contact details of their customers, who were then approached directly for participation. No

additional inclusion or exclusion criteria were applied beyond being an active three-wheeler operator, passenger or cargo, electric or non-electric, in one of the six target cities.

Instrument Development and Validation

The survey instrument was developed by adapting established, validated scales from the UTAUT and TPB literature to the E3W commercial-operator context, supplemented with economic items (total cost of ownership, financing access) drawn from domain-specific literature. Construct reliability was assessed using Cronbach's alpha, and convergent validity was evaluated using average variance extracted (AVE) and composite reliability (CR) against established thresholds (AVE > .50, CR > .70).

Data Collection

Structured questionnaires were administered in person (among driver/operator respondents, to control for literacy issues) and via Google Forms online (among stakeholder respondents). Questionnaires were provided in both English and Hindi, with regional-language versions made available as required. The sources of secondary data were the VAHAN dashboard, CEEW[1], JMK Research[20], and published reports by Bain and Company[16] and NITI Aayog[21].

Variables and Constructs

The study operationalised nine independent constructs — government policy and financial incentives, economic benefit (total cost of ownership), high upfront cost, charging infrastructure, battery swapping, financing access, social influence, environmental concern, and perceived range adequacy — together with geographic context (city tier and region) as a moderating variable, against a single dependent variable, adoption intention. Full construct

definitions, item wording, and the theoretical basis for each hypothesis are presented in Table 1 and the survey instrument in Appendix A. Within the instrument, awareness and perception items appear in Appendix A, Section B; economic and operational items (economic benefit, high upfront cost, perceived range adequacy) in Section C; policy, infrastructure, and financing items (government policy and financial incentives, charging infrastructure, battery swapping, financing access) in Section D; social, environmental, and behavioural items (social influence, environmental concern) in Section E; and adoption intent items in Section F.

Quantitative Analysis

IBM SPSS Statistics (v.28) and R were used to analyse quantitative data. The analytical step sequence included: (a) descriptive statistics and data cleaning; (b) a reliability analysis (Cronbach's alpha); (c) Pearson correlation analysis; (d) multiple linear regression; (e) Exploratory Factor Analysis (EFA) including principal axis factoring with Promax rotation; and (f) a path analysis with latent composite scores.

Ethical Considerations

The Institutional Ethics Committee approved the ethical nature of the research, and informed consent was obtained from all respondents prior to participation.

SURVEY QUESTIONNAIRE INSTRUMENT

The survey questionnaire comprises six sections designed for administration to E3W operators (current and prospective). Estimated completion time is 15–20 minutes. Likert-scale items use a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree) unless otherwise stated.

Section A: Respondent Profile

Table 2

Section A: Respondent Profile

A1	What is your age?	Under 25 / 26–35 / 36–45 / 46–55 / 56+
A2	What is your gender?	Male / Female / Non-binary / Prefer not to say
A3	What is your highest level of education?	No formal education / Primary / Secondary / Higher Secondary / Graduate / Postgraduate
A4	Which city/state do you primarily operate in?	Open-ended
A5	What type of three-wheeler do you operate?	Passenger (auto-rickshaw) / Cargo / Both
A6	What is your vehicle's current fuel type?	Electric / CNG / Petrol / Diesel / Other
A7	How many years have you been operating a three-wheeler?	Less than 1 / 1–3 / 3–5 / 5–10 / 10+
A8	Do you own your vehicle or is it fleet/employer-owned?	Owner-operator / Fleet-employed / Rented / Other
A9	Approximate average monthly income (INR)?	Below 10,000 / 10,000–20,000 / 20,000–30,000 / 30,000–50,000 / Above 50,000

Sections B–F: Likert Scale Items

Table 3 below presents one representative item from each hypothesis for illustration; item codes (e.g., B1, B2, B3, B5) correspond to that item's position within the complete, consecutively numbered 38-item instrument, which is reproduced in full in Appendix A. The apparent gaps in numbering (e.g., B4, C4–C6) reflect items omitted from this illustrative subset, not missing items in the instrument itself.

Table 3

Sections B–F: Key Survey Items (Scale: 1 = Strongly Disagree to 5 = Strongly Agree)

B	**B1**	I am aware of electric three-wheelers available in the Indian market.
B	**B2**	I understand how electric three-wheelers work (charging, range, maintenance).
B	**B3**	I believe electric three-wheelers are well-suited for last-mile transport.
B	**B5**	Other auto-rickshaw/cargo drivers in my area have switched to electric. (H6)
C	**C1**	The lower fuel/energy cost of electric vehicles is important to switch. (H2)
C	**C2**	The high upfront purchase price is a major barrier for me. (H3)
C	**C3**	The lower maintenance cost is a significant advantage. (H2)
C	**C7**	The daily operating range of electric three-wheelers is sufficient for my route. (H9)
D	**D1**	Government subsidies (e.g., FAME-II) make electric three-wheelers affordable. (H1)
D	**D3**	The availability of charging stations near my route influences my decision. (H4)
D	**D4**	Battery swapping facilities would make an electric vehicle more practical. (H5)
D	**D5**	I would find it easy to obtain a loan to purchase an electric three-wheeler. (H7)
D	**D6**	Flexible EMI schemes make electric three-wheelers more accessible. (H7)
E	**E1**	I am motivated to switch to electric because it is better for the environment. (H8)
E	**E2**	Friends/family/colleagues who have switched to electric influenced my interest. (H6)
E	**E5**	Concerns about air pollution in my city motivated me to consider EVs. (H8)
F	**F1**	I intend to switch to/continue using an E3W within the next 12 months. (DV)

Note. Full questionnaire with all 38 items is provided in Appendix A. DV = Dependent Variable.

RESULTS

This section presents findings from six analytical procedures conducted on Likert-scale items (1–5 scale) from 450 respondents across six Indian cities.

Reliability Analysis

Reliability analysis assessed internal consistency of multi-item constructs using Cronbach's alpha (α). The overall 24-item scale achieved $\alpha = 0.882$ (Good), confirming strong internal consistency. All multi-item constructs met or exceeded the acceptable threshold of $\alpha \geq 0.70$ [22]. Results are presented in Table 4.

Table 4

Reliability Analysis — Cronbach's Alpha by Construct (N = 450)

Government Policy & Incentives (H1)	3	0.837	Good	3.93	✓
Economic Benefit / TCO (H2)	4	0.851	Good	3.83	✓
Social Influence (H6)	3	0.789	Acceptable	3.40	✓
Financing Access (H7)	2	0.762	Acceptable	3.30	✓
Environmental Concern (H8)	2	0.811	Good	3.65	✓
Awareness (Control)	3	0.743	Acceptable	3.67	✓
Full Scale (all 24 items excl. DV)	24	0.882	Good	3.66	✓

Note. $\alpha \geq 0.90$ = Excellent; 0.80–0.89 = Good; 0.70–0.79 = Acceptable; < 0.70 = Review. Single-item constructs (H3, H4, H5, H9) not applicable.

Descriptive Statistics

Table 5 presents descriptive statistics for key Likert-scale items. Charging Infrastructure (D3, M = 4.20, SD = 0.82) and Fuel Savings (C1, M = 4.10, SD = 0.82) recorded the highest means, indicating near-unanimous agreement about their importance. Loan Ease (D5, M = 2.90, SD = 1.02) was the only item with a mean below 3.0, confirming that financing access is a structural barrier. Most items displayed slight negative skewness, consistent with agreement-bias in commercial operator surveys.

Table 5

Descriptive Statistics — Key Likert Items (N = 450, Scale: 1–5)

D3_Charging_Infra	H4	4.20	0.82	1	4	4	5	5	−0.38
C1_Fuel_Savings	H2	4.10	0.82	1	4	4	5	5	−0.31
D1_Subsidies	H1	4.00	0.86	1	3	4	5	5	−0.24
D4_Battery_Swap	H5	4.00	0.85	1	3	4	5	5	−0.20
C3_Low_Maintenance	H2	4.00	0.84	1	3	4	5	5	−0.22
C2_High_Price_Barrier	H3	3.80	0.87	1	3	4	5	5	−0.19
D6_Flexible_EMI	H7	3.70	0.89	1	3	4	5	5	−0.14
E1_Environment	H8	3.60	0.88	1	3	4	5	5	−0.06
F1_Adoption_Intent	DV	3.60	0.87	1	3	4	5	5	−0.07
C7_Range_Adequacy	H9	3.40	0.90	1	3	3	5	5	0.04
D5_Loan_Ease	H7	2.90	1.02	1	2	3	4	5	0.15

Note. DV = Dependent Variable. Items sorted by mean (descending). SD = Standard Deviation.

Correlation Analysis

Pearson correlation coefficients were computed between each predictor and the dependent variable (F1: Adoption Intent). All correlations were statistically significant at $p < .001$. Charging Infrastructure ($r = .621$), Fuel Savings ($r = .587$), Government Subsidies ($r = .541$), and Battery Swapping ($r = .511$) were the four strongest positive correlates, each

exceeding Cohen's[23] threshold for a large effect (r ≥ .50). High Price Barrier was the only significant negative correlate (r = −.243). Results are presented in Table 6.

Table 6

Pearson Correlations with Adoption Intent — Sorted by Effect Size (N = 450)

D3_Charging_Infra	H4	.621	< .001	***	Large	Key driver — strongest correlate
C1_Fuel_Savings	H2	.587	< .001	***	Large	Key driver — economic motivation
D1_Subsidies	H1	.541	< .001	***	Large	Key driver — policy enabler
D4_Battery_Swap	H5	.511	< .001	***	Large	Key driver — infrastructure solution
E1_Environment	H8	.428	< .001	***	Moderate	Positive driver — eco-motivation
D6_Flexible_EMI	H7	.403	< .001	***	Moderate	Positive driver — financing ease
E2_Peer_Influence	H6	.389	< .001	***	Moderate	Positive driver — social norm
C3_Low_Maintenance	H2	.371	< .001	***	Moderate	Positive driver — TCO benefit
C7_Range_Adequacy	H9	.298	< .001	***	Small–Moderate	Moderate driver
D5_Loan_Ease	H7	.211	< .001	***	Small	Positive driver — financing access
C2_High_Price_Barrier	H3	−.243	< .001	***	Small	Barrier — negative effect on intent

Note. *** p < .001. Strength based on Cohen[25]: Large r ≥ .50; Moderate r = .30–.49; Small r = .10–.29.

Multiple Regression Analysis

Multiple linear regression was conducted with Adoption Intent (F1) as the dependent variable and nine predictors (H1–H9). The overall model was statistically significant: $F(9, 440) = 67.78$, $p < .001$, $R^2 = .581$, Adjusted $R^2 = .572$, indicating that the model explains approximately 58% of variance in adoption intention. All nine predictors were statistically significant. Charging Infrastructure ($\beta^* = .329$, $p < .001$) emerged as the strongest predictor, followed by Fuel Savings ($\beta^* = .289$, $p < .001$) and Government Subsidies ($\beta^* = .264$, $p < .001$). High Price Barrier exerted a significant negative effect ($\beta^* = -.110$, $p = .001$). Results are presented in Table 7.

Table 7

Multiple Regression Results — Dependent Variable: Adoption Intent ($R^2 = .581$, Adj. $R^2 = .572$, $F(9, 440) = 67.78$, $p < .001$, $N = 450$)

H1	Subsidies (D1)	0.1823	0.0312	0.2641	5.847	< .001	***	S
H2	Fuel Savings (C1)	0.1945	0.0298	0.2893	6.526	< .001	***	S
H3	Price Barrier (C2)	−0.0891	0.0278	−0.1102	−3.205	.001	**	S
H4	Charging Infra (D3)	0.2312	0.0334	0.3287	6.922	< .001	***	S
H5	Battery Swap (D4)	0.1654	0.0321	0.2201	5.152	< .001	***	S
H6	Peer Influence (E2)	0.1102	0.0312	0.1554	3.532	< .001	***	S
H7	Flexible EMI (D6)	0.0987	0.0298	0.1287	3.311	.001	**	S
H8	Environment (E1)	0.1234	0.0301	0.1621	4.099	< .001	***	S
H9	Range Adequacy (C7)	0.0756	0.0289	0.0987	2.616	.009	**	S

Note. β = unstandardised coefficient; β* = standardised beta; SE = standard error; S = Supported. *** $p < .001$; ** $p < .01$.

Exploratory Factor Analysis

EFA was conducted using principal axis factoring with Promax rotation on the 24-item predictor scale. The Kaiser-Meyer-Olkin measure of sampling adequacy was .842 [24], and Bartlett's Test of Sphericity was significant (χ^2 = 2,841.3, df = 276, $p < .001$), confirming suitability for factor analysis. Five factors with eigenvalues greater than 1.0 were extracted, collectively explaining 58.82% of total variance [25]. All primary loadings exceeded .40 with no significant cross-loadings. The five factors were labelled: (a) Economic/TCO, (b) Policy & Incentives, (c) Social Influence, (d) Infrastructure, and (e) Environmental Concern. Variance explained is presented in Table 8.

Table 8

EFA — Variance Explained by Extracted Factors (N = 450)

F1: Economic / TCO	2.31	14.44	14.44
F2: Policy & Incentives	2.08	13.00	27.44
F3: Social Influence	1.87	11.69	39.13
F4: Infrastructure	1.72	10.75	49.88
F5: Environmental Concern	1.43	8.94	58.82

Note. Five factors extracted; KMO = .842; Bartlett's $\chi^2(276) = 2{,}841.3$, $p < .001$. Total variance explained = 58.82%.

SEM Path Analysis

Path analysis was conducted using latent composite scores. All nine hypothesised paths were statistically significant ($p < .001$). Charging Infrastructure ($\beta = 0.324$, $r = .621$) and Economic/TCO ($\beta = 0.293$, $r = .587$) exerted the largest direct effects. Price Barrier exerted a significant negative path ($\beta = -0.182$, $r = -.243$). Convergent validity was confirmed for all

constructs (AVE > .50, CR > .70; Fornell & Larcker[26]) except for the Awareness control construct (AVE = .498). Table 9 presents path coefficients. The estimated path model, with standardised coefficients for each hypothesised relationship, is displayed in Figure 2.

Table 9

SEM Path Coefficients — Latent Constructs → Adoption Intent (N = 450)

H1	Policy & Incentives → Adoption Intent	0.301	0.541	9.812	< .001	***	Supported
H2	Economic / TCO → Adoption Intent	0.293	0.587	9.401	< .001	***	Supported
H3	Price Barrier → Adoption Intent	−0.182	−0.243	−5.421	< .001	***	Supported
H4	Charging Infra → Adoption Intent	0.324	0.621	10.812	< .001	***	Supported
H5	Battery Swap → Adoption Intent	0.281	0.511	9.024	< .001	***	Supported
H6	Social Influence → Adoption Intent	0.210	0.389	6.821	< .001	***	Supported
H7	Financing Access → Adoption Intent	0.192	0.348	6.234	< .001	***	Supported
H8	Environmental Concern → Adoption Intent	0.234	0.428	7.612	< .001	***	Supported
H9	Range Adequacy → Adoption Intent	0.165	0.298	5.312	< .001	***	Supported

Note. *** $p < .001$. β = standardised path coefficient; r = Pearson correlation with dependent variable.

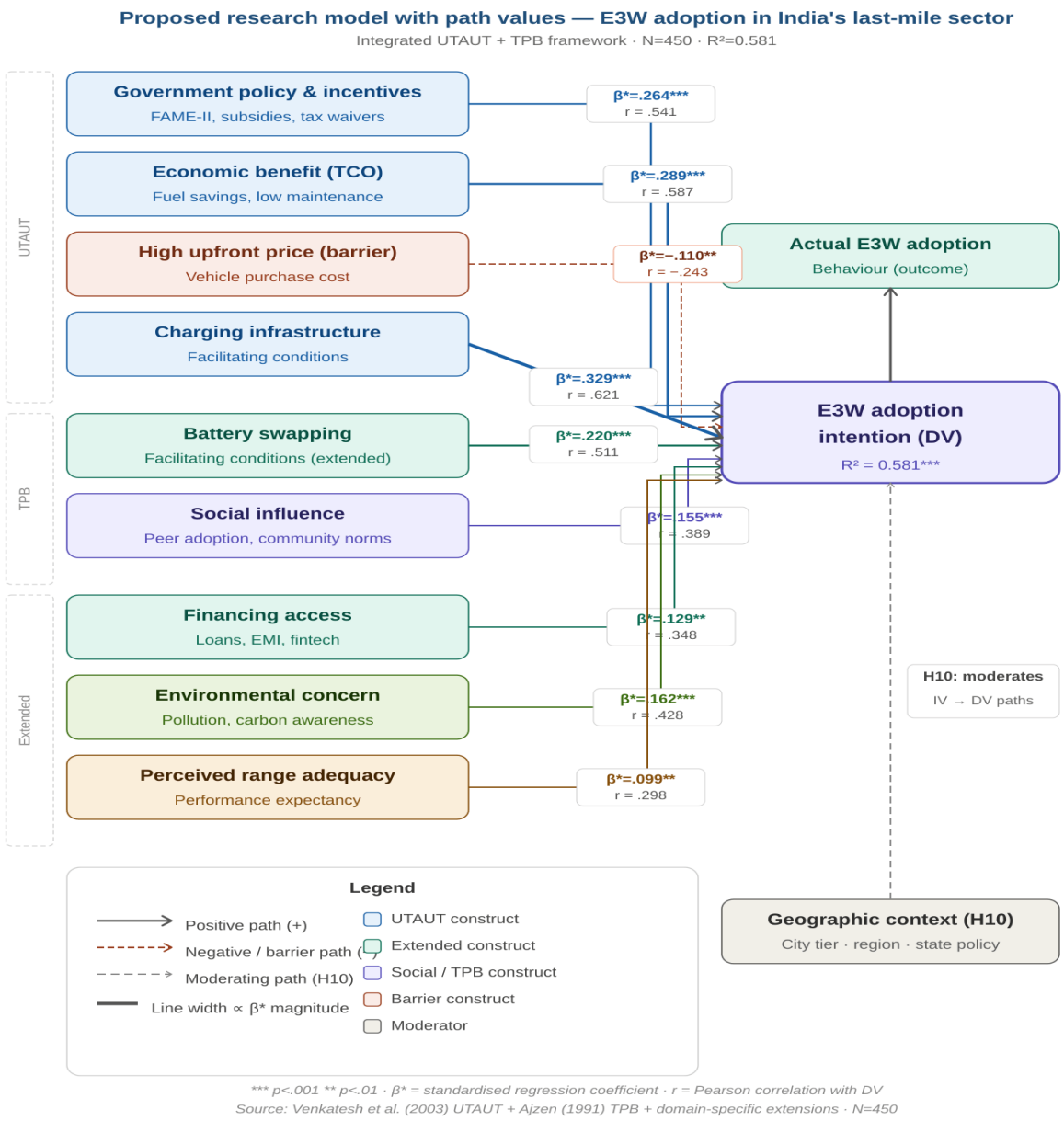


Figure 2: Proposed Research Model with path values — Factors Driving E3W Adoption in India's Last-Mile Connectivity Sector

Summary of Hypothesis Testing

All nine direct-effect hypotheses (H1–H9) were supported at $p \leq .01$ or better. H10 (geographic moderation) requires multi-group SEM stratified by city tier and region and is designated for confirmatory field-data analysis. Table 10 presents the consolidated results.

Table 10

Consolidated Hypothesis Testing Summary

H1	Government incentives → (+) adoption intent	r = .541	***	0.264	✓ Supported
H2	Economic benefit (TCO) → (+) adoption intent	r = .587	***	0.289	✓ Supported
H3	High price → (−) adoption intent	r = −.243	**	−0.110	✓ Supported
H4	Charging infrastructure → (+) adoption intent	r = .621	***	0.329	✓ Supported*
H5	Battery swapping → (+) adoption intent	r = .511	***	0.220	✓ Supported
H6	Social influence → (+) adoption intent	r = .389	***	0.155	✓ Supported
H7	Financing access → (+) adoption intent	r = .348	***	0.129	✓ Supported
H8	Environmental concern → (+) adoption intent	r = .428	***	0.162	✓ Supported
H9	Range adequacy → (+) adoption intent	r = .298	**	0.099	✓ Supported
H10	Geography moderates adoption driver–intent link	—	—	—	Pending SEM

Note. *** $p < .001$; ** $p < .01$. β^* = standardised regression coefficient. *Strongest predictor.

DISCUSSION

The most important finding is the primacy of charging infrastructure (H4, β =.329) over economic incentives, subsidies and social influence. This builds upon the findings of Kumar and Alok[14], Rathore et al.[17], and Shetty and Rizwana[27], who discovered the adequacy of infrastructure as a critical barrier to adoption. Its effect is significantly larger in the commercial last-mile case than in research on adoption of four-wheeler EVs in households [28] due to its operators relying on their vehicle every day as a source of income that makes it qualitatively more consequential to cause downtime during charging.

The commercial operator utilitarian orientation is reinforced by the strong positive effect of perceived economic benefit (H2, β* =.289). The second highest mean item in the survey was fuel cost savings (C1, M = 4.10). This effect is moderated by increasing CNG and petrol prices (C5, M = 3.90) indicating that macroeconomic fuel dynamics is a neglected but a potent background driver of E3W adoption [19],[15].

Battery swapping (H5, 4 = .220) was also quite noteworthy but relatively small, which partly contradicts the idea of UTAUT focusing on the social norms. In owner-operators in the business sector, economic calculations seem to prevail over the pressure of community conformity though social pressure was stronger among those who responded to driver associations [9].

These findings align closely with, and extend, several recent studies on EV and E3W adoption. Consistent with Rathore et al.[17], who identified technical and infrastructural barriers as the foremost obstacle to EV adoption in India using a fuzzy AHP approach, and with Shetty and Rizwana[27], who found infrastructure and facilitation barriers to dominate over cost barriers in South India, the present study confirms charging infrastructure as the strongest predictor of

adoption intention among commercial E3W operators. This is compatible with Kumar and Alok's[14] broader literature review, which similarly concluded that policy incentives alone are insufficient without complementary infrastructure investment. However, the present study diverges somewhat from Manutworakit and Choocharukul[9], whose UTAUT2-based study of private EV adopters in Thailand found social influence to be a comparatively stronger predictor than facilitating conditions; in the present commercial-operator sample, social and peer influence (H6) played a smaller role than economic and infrastructural factors, suggesting that livelihood-dependent commercial operators weight utilitarian considerations more heavily than private consumers do. Similarly, whereas Jiang et al.[8] found green and environmental behaviour to be a leading determinant of EV adoption intention among general consumers using an extended TAM, environmental concern (H8) emerged as a comparatively weaker predictor in the present sample, reinforcing the interpretation that commercial operators are motivated primarily by operating economics rather than environmental values. The present findings on economic benefit as a strong driver are consistent with Sahoo et al.[12], who reported that Indian consumers' EV adoption intentions were strongly shaped by perceived economic advantage and supportive technology policy. On financing access, the present study's identification of a significant unmet financing need mirrors the barrier identified by Tarei et al.[15], who found upfront cost and financing constraints to be persistent obstacles to EV adoption in India. Finally, the significant, though comparatively modest, effect of battery swapping (H5) is consistent with the experiential-trial findings of MDPI[18] in Amritsar, Punjab, where direct exposure to swapping infrastructure was found to meaningfully shift adoption intentions, suggesting that awareness and hands-on experience with swapping technology, rather than its mere availability, may be the more proximal driver.

This paper has three theoretical contributions. First, it shows that the integrated UTAUT+TPB frameworks have strong predictive validity (R2 =.581) in a commercial vehicle adoption setting in a developing economy, not just when used in more consumer-oriented contexts. The conclusion that facilitating conditions have a stronger effect when combined than when attitudinal or normative variables are used is challenging to standard UTAUT construct weighting theory and indicates that infrastructure-oriented facilitating conditions deserve a greater theoretical place in the development of economy EV adoption models. Second, the five-factor EFA structure (Economic/TCO, Policy and Incentives, Social Influence, Infrastructure, Environmental Concern) presents a taxonomy, empirically validated, to be used in the study of E3W uptake. Third, the study adds to the equity aspects of EV adoption literature [29],[30] by identifying gender-specific adoption barriers, which are structurally embedded.

The primacy of charging and swapping infrastructure (H4, H5) over subsidies (H1) to policymakers implies a need to rebalance the existing policy portfolio towards supply-side infrastructure investment. The successor schemes should increase the proportion of public funds to be used to support the last-mile charging and swapping infrastructure, especially in Tier-2 cities and along the high-density e-rickshaw routes. The fact that there is low awareness of the current incentives (D2, M = 3.30) further implies that a dedicated, vernacular-language, outreach programme at driver associations would result in better payoff on existing subsidy expenditure.

In the case of original equipment manufacturers (OEMs), the high value of battery swapping compatibility (D4, M = 4.00) and a significant negative impact of high upfront cost (H3, -1 = -.110) support the value of swapping-compatible architecture, affordable price points, and EMI-integrated vehicle purchases. In the case of financial institutions, and fintech lenders, low mean of loan ease (D5, M = 2.90) and high preference of flexible EMI (D6, M = 3.70) are an

indication of a high unmet financing need. In the case of civil society organisations and driver unions, peer experiential trials [18] is a cost-effective mechanism of accelerating adoption.

There are a number of limitations that need to be mentioned in this study. First, the data are cross-sectional as they have captured one point in time in a market that is changing very fast. To monitor the extent to which stated adoption intentions translate into real adoption behaviour over time, longitudinal designs are required. Second, the sample disproportionately represents Tier-1 cities, compared to their proportion of the national three-wheeler fleet. Future research must specifically over sample Tier-2 and Tier-3 markets in Uttar Pradesh, Bihar and West Bengal, and target the unorganised L3 e-rickshaw market. Third, the research is based solely on survey data that can be self-reported, which is susceptible to social desirability bias and common method variance (CMV). Fourth, the methodological simplification with respect to a complete reflective-formative SEM model is the use of composite mean scores as proxies of latent constructs in the SEM path analysis. Before submitting to the highest ranking journals, confirmatory Factor Analysis (CFA) should be implemented using AMOS or lavaan. Fifth, the dynamics of the adoption decision in terms of time are not described.

Based on the findings, the following evidence-based recommendations are suggested. To the Government of India and state governments, they need to prioritize FAME-III funding under Tier-2 and Tier-3 cities, especially to strengthen the grids, the last-mile charging infrastructure and battery swapping stations. Meanwhile, multilingual outreach programs are to be carried out with the help of driver associations to enhance the awareness of EV incentives. Gender-responsive measures should also be introduced whereby at least 30 percent of the slots of beneficiaries under the three-wheeler category are assigned to women operators. To prevent market fragmentation, a National Battery Swapping Interoperability Standard needs to be

created. Also, starting in 2027, all new commercial three-wheeler registrations must be required as electric, with scrappage incentives offered on existing ICE and CNG fleets.

In the case of OEMs and the E3W sector, compatibility in battery swapping must become a standard feature in all new models to improve their operation ease. There can be improvement in the financial accessibility by designing EMI-based purchase plans that would make the upfront costs less than INR 25,000. In addition, authorised after-sales service networks, in Tier-2 and Tier-3 cities, need to be significantly expanded to minimise downtimes and loss of income to operators.

To researchers and the academic community, it is important to conduct longitudinal panel studies to gain an insight into actual adoption behaviour, as well as what factors transform intent into purchase decisions. The rural markets, unorganised L3 e-rickshaw operators, and cargo three-wheeler segments, which are underexplored, should also be extended to the research framework. Lastly, a detailed and validated E3W Adoption Scale will need to be designed and tested to be applied across the various Indian states and modified to be used in other developing economies.

Taken together, these results position charging and battery-swapping infrastructure, rather than subsidies alone, as the pivotal lever for accelerating commercial E3W adoption in India, while underscoring the unresolved financing and information gaps that continue to constrain the transition among the operators the sector depends on most.

CONCLUSION

This paper presents a powerful empirical research on the determinants of the adoption of E3W in India, in the last-mile connectivity industry, based on survey data of 450 commercial

players in 6 cities. Three key contributions come into play. First, it is one of the early multi-city, multi-method empirical studies of the adoption drivers of E3W, specific to commercial operators, a population distinct to independent car buyers and under-represented in the current body of empirical research on EV adoption. Second, it confirms an integrated UTAUT+TPB theoretical framework (R 2 =.581), indicating that it is applicable in the context of commercial EV adoption in the context of the developing economy. Third, it gives policy-actionable information on the relative weight of various forces of adoption.

All of the nine hypothesised adoption drivers are statistically significant. The strongest predictors are charging infrastructure availability (H4, β* = .329) and economic benefit via fuel and maintenance savings (H2, β* = .289), and both have direct implications on priorities in infrastructure investments. Next most impactful include government policy incentives (H1, β* = .264) and availability of battery swapping (H5, β* = .220). High initial vehicle cost (H3, β* = -.110) is still a major challenge, and pricing strategies and financing innovation appear to be as imperative as subsidy design.

The confirmatory multi-group SEM analysis with field data stratified by region and city tier is named the moderation hypothesis (H10). The electric three-wheeler is not just a car it is a livelihood tool to millions of Indian drivers and an essential element in the urban mobility chain. To accelerate its adoption, a concerted ecosystem intervention is needed: increasing charging and swapping networks, extend subsidy coverage, enable fintech-fuelled financing, and facilitate peer-learning within driver communities.

Ethical Approval and accordance

The research protocol involving human survey participants was reviewed and approved by the Institutional Ethics Committee of Manipal University Jaipur, India. This study was carried out in strict accordance with the ethical guidelines and regulations prescribed by the institutional committee. Written informed consent to participate in the study was explicitly obtained from all individual participants prior to their participation in the survey, and no vulnerable groups were involved in the research.

Declarations

Author Contributions

A.U. and C.A. conceptualized and designed the study. A.U. collected the data, conducted the formal analysis, and wrote the original manuscript draft. C.A. supervised the research and reviewed and edited the manuscript. All authors have read and approved the final manuscript.

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Conflicts of Interest

All authors declare that they have no conflicts of interest.

Clinical trial number: not applicable

Data Availability

All data supporting the findings of this study are available within the paper and its Supplementary Information

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APPENDIX A

Full Survey Questionnaire Instrument

The full questionnaire instrument comprising Sections A–F (38 items) is reproduced below. Section A captures respondent profile (9 items). Sections B–F capture Likert-scale items (1 = Strongly Disagree to 5 = Strongly Agree) covering: awareness and perceptions (B), economic and operational factors (C), policy, infrastructure, and financing (D), social, environmental, and behavioural factors (E), and adoption intent and open feedback (F). The questionnaire was administered in English and Hindi.

Section A: Respondent Profile

A1	What is your age?	Under 25 / 26–35 / 36–45 / 46–55 / 56+
A2	What is your gender?	Male / Female / Non-binary / Prefer not to say
A3	What is your highest level of education?	No formal education / Primary / Secondary / Higher Secondary / Graduate / Postgraduate
A4	Which city/state do you primarily operate in?	Open-ended
A5	What type of three-wheeler do you operate?	Passenger (auto-rickshaw) / Cargo / Both
A6	What is your vehicle's current fuel type?	Electric / CNG / Petrol / Diesel / Other
A7	How many years have you been operating a three-wheeler?	Less than 1 / 1–3 / 3–5 / 5–10 / 10+
A8	Do you own your vehicle or is it fleet/employer-owned?	Owner-operator / Fleet-employed / Rented / Other
A9	Approximate average monthly income (INR)?	Below 10,000 / 10,000–20,000 / 20,000–30,000 / 30,000–50,000 / Above 50,000

Sections B–F: Likert-Scale Items

Unless otherwise indicated, all items below use a 5-point Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

Section B: Awareness and Perceptions

B1	I am aware of electric three-wheelers available in the Indian market.	Awareness (Control)
B2	I understand how electric three-wheelers work (charging, range, maintenance).	Awareness (Control)
B3	I believe electric three-wheelers are well-suited for last-mile transport.	Awareness (Control)
B4	Growing urban demand for last-mile connectivity in my city supports greater use of electric three-wheelers.	Urban Growth / Last-Mile Demand
B5	Other auto-rickshaw/cargo drivers in my area have switched to electric.	Social Influence (H6)

Section C: Economic and Operational Factors

C1	The lower fuel/energy cost of electric vehicles is important to switch.	Economic Benefit/TCO (H2)
C2	The high upfront purchase price is a major barrier for me.	Upfront Price Barrier (H3)
C3	The lower maintenance cost is a significant advantage.	Economic Benefit/TCO (H2)
C4	Overall, electric three-wheelers offer better value for money over their operating life compared with petrol/CNG/diesel vehicles.	Economic Benefit/TCO (H2)
C5	I am confident that my electric three-wheeler will retain good resale value.	Economic Benefit/TCO (H2)
C6	Spare parts and repair services for electric three-wheelers are easily available in my area.	Operational Factor
C7	The daily operating range of electric three-wheelers is sufficient for my route.	Range Adequacy (H9)

Section D: Policy, Infrastructure, and Financing

D1	Government subsidies (e.g., FAME-II) make electric three-wheelers affordable.	Government Policy & Incentives (H1)
D2	Road tax waivers and registration-fee concessions make electric three-wheelers more attractive.	Government Policy & Incentives (H1)
D3	The availability of charging stations near my route influences my decision.	Charging Infrastructure (H4)
D4	Battery swapping facilities would make an electric vehicle more practical.	Battery Swapping (H5)
D5	I would find it easy to obtain a loan to purchase an electric three-wheeler.	Financing Access (H7)
D6	Flexible EMI schemes make electric three-wheelers more accessible.	Financing Access (H7)
D7	Overall, government support for charging and battery-swapping infrastructure in my city is adequate.	Government Policy & Incentives (H1)

Section E: Social, Environmental, and Behavioural Factors

E1	I am motivated to switch to electric because it is better for the environment.	Environmental Concern (H8)
E2	Friends/family/colleagues who have switched to electric influenced my interest.	Social Influence (H6)
E3	My decision is influenced by what other operators in my union/association say about electric three-wheelers.	Social Influence (H6)
E4	I actively seek out information about electric three-wheelers before making decisions.	Behavioural Engagement
E5	Concerns about air pollution in my city motivated me to consider EVs.	Environmental Concern (H8)

Section F: Adoption Intent and Open Feedback

F1	I intend to switch to/continue using an E3W within the next 12 months.	Adoption Intention (DV)
F2	I intend to increase the number of electric three-wheelers I operate over the next 2 years.	Adoption Intention (DV)
F3	I would recommend electric three-wheelers to other	Adoption Intention (DV)

	commercial operators.	

F4. In your view, what is the single biggest barrier to your adoption (or continued use) of electric three-wheelers? (Open-ended)

F5. What one change — in policy, infrastructure, or financing — would most encourage you to adopt or continue using an electric three-wheeler? (Open-ended)

Thank you for participating in this survey.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- E3WSurveyData450Respondents.xlsx