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SUSTAINABLE LAST MILE DELIVERY: ARE E-CONSUMERS READY FOR COURIER SERVICES BY ELECTRIC VEHICLES?

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Abstract. Driven by the expansion of e-commerce and rising environmental awareness, this study is set within the context of growing market demand for sustainable and low-emission solutions in the courier industry. The aim of the article is to verify the readiness of e-consumers and the determinants to use an eco-innovative method of last-mile delivery by electric vehicles (EVs) in the courier services. A quantitative authors' conceptual model including Technology Readiness and Technology Acceptance Model was developed and verified. Perceived ease of use significantly impacts perceived usefulness, and both strongly predict adoption intention. The growing shift toward electric fleets among couriers aligns with e-consumers' readiness, however, the study offers important insights. Technological optimism influences adoption of last-mile deliveries by EV indirectly, e-consumers' innovation and trust show an unsatisfactory effect. Although environmental awareness improves perceptions of use, it does not directly translate into higher adoption intent. The findings emphasise the importance of a holistic strategy that combines technological functionality, environmental values, and realistic expectations to promote the integration of EVs into courier logistics. Providers should focus on operational improvements and education, presenting EVs above all as efficient and easy to integrate with existing logistics systems, striving for their integration with sustainability and circularity.

Keywords: sustainable transportation, sustainable distribution, eco-innovation, eco-innovativeness, transport management, electric vehicles market, courier services, Technology Acceptance Model, technology adoption.

JEL Classification: L81, L91, M21, O32, O33, Q55, Q56, R41.

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1. Introduction

A key element of Poland's economic growth is sustainable transport. The *Strategy for Sustainable Transport Development by 2030* aims to boost accessibility, safety, and efficiency through innovative and eco-friendly systems, especially low-emission Electric Vehicles (EVs). These measures are intended to improve the energy efficiency of the transport sector and reduce its negative environmental and climate-related impacts (Ministerstwo Infrastruktury, 2019). Aligned with Polish Energy Policy 2040, Poland declares to achieve at least a 23% share of renewable energy sources in gross final energy consumption in 2030, including 14% in transport (Ministerstwo Klimatu i Środowiska, 2021). One of the most rapidly developing segments of the transport sector is the Courier, Express, and Parcel (CEP) market. While still in a growth phase, compared to Western European countries, the Polish CEP industry has seen

substantial changes including mergers with global companies and increased employment Despite economic uncertainties, the Polish CEP market benefits from the country's geographical location, qualified workforce, and developed transport infrastructure. The e-commerce boom has significantly impacted Poland's courier service market, driving its rapid growth. This expansion is driven by digital transformation, increased mobility, and the popularity of portable devices (Gulc, 2020). The COVID-19 pandemic further accelerated the use of courier services (Sułkowski et al., 2022). The share of purchases made via the internet has been systematically growing recently in Poland (Macioszek & Jurdana, 2022). As Eurostat reported, the number of e-customers in Europe has increased dynamically, as 77% of Internet users ordered goods or services online in 2024, while in Poland it was 75% compared to 59% in 2014 (Eurostat, 2025). To remain competitive, courier companies are focusing on improving service quality. The key factors influencing customer's perception of service quality include reliability, visual identification, service complexity, relational capital, social responsibility, responsiveness, and technical quality have been identified as crucial dimensions that affect courier service quality in e-commerce (Gulc, 2020).

The rapid growth of e-commerce in recent years has significantly impacted logistics and transportation, particularly affecting various last mile delivery modes especially in urban areas. E-commerce produces considerably more packaging waste and higher CO_2 emissions, especially from last-mile delivery and returns than traditional retail, yet it also presents significant opportunities to reduce emissions through fleet electrification, optimized delivery routes, and the use of renewable energy in data centres (Krajewska et al., 2025). At the same time, numerous European regulations have introduced strict environmental restrictions aimed at reducing air and noise pollution in urban areas. In response, the logistics and transportation sector must adopt more efficient and environmentally friendly methods for delivering goods (Ilin et al., 2023). However, the results of previous studies on the preferences for last-mile delivery alternatives, has revealed that the type of delivery vehicle influences choices more than environmental impact disclosures (Amaya et al., 2025). Similarly, the issues of carbon footprint and transportation by EVs are perceived by on-line customers in Poland as relatively less important while choosing the delivery, however the growing ecological trend in e-commerce is becoming increasingly noticeable. According to the Report E-commerce 2024, 41% of consumers pay attention to the environmental impact of delivery methods, reflecting rising environmental awareness. Environmentally friendly delivery, carried out for example by EVs or using eco-friendly packaging, motivates as many as 51% of respondents to make purchases, although currently only about 19% use such options. Therefore, companies have an opportunity to build a competitive advantage by investing in sustainable logistics solutions, which are especially value as 25% of surveyed consumers consider EVs transportation an important factor (Gemius, 2024).

The adoption of EVs in the courier sector in Poland is gaining attention due to increasing environmental regulations and the need for sustainable urban logistics and transport carried out to a greater extent based on alternative fuels, including for example electricity, hydrogen or biofuels (Simionescu et al., 2017). Research explores the feasibility, benefits, and challenges of integrating electric vehicles into courier fleets in Poland, focusing on economic, environmental, and operational aspects. While electrification could potentially reduce carbon emissions by 24% and decrease operational costs, the country's heavy reliance on fossil

fuels complicates the environmental benefits (Zamasz et al., 2021). The implementation of electromobility in Polish cities is hindered by slow growth in EVs numbers, insufficient charging infrastructure, and limited municipal budgets (Brodowicz & Stankowska, 2021). Poland belongs to the group of countries with the lowest proportion of EVs among all vehicles (0.1% with the EU average of 1.1%) and, at the same time, has one of the highest ratios of the number of cars per 1000 inhabitants (662 with the EU average of 560) (European Automobile Manufacturers' Association, 2022). Moreover, the key challenges associated with e-vehicles adoption include high infrastructure costs, a limited number of charging stations, restricted driving range often referred to as range anxiety, and battery performance issues (Alanazi, 2023). Despite these challenges, electromobility is seen as a tool for managing CO_2 emissions, with potential reductions in other pollutants such as CO and NO_x (Tucki et al., 2019). Switching to EVs in courier fleets significantly reduces harmful emissions, contributing to improved urban air quality and compliance with stricter emission standards. Economic analyses indicate that while initial investments and operational adjustments are necessary, long-term benefits include lower operating costs and reduced environmental impact (Alanazi, 2023). Economic and technological factors are identified as key stimulants for fleet electrification in the transport, shipping, and logistics sector (Raźniewska & Wronka, 2024). The use of renewable energy sources further enhances the sustainability of courier operations (Patella et al., 2021). Studies show that electric delivery vehicles can be integrated into courier operations, especially for short-distance urban deliveries (Jedliński & Nürnberg, 2022). The integration of EVs in last-mile delivery is increasingly recognized as a sustainable solution to the challenges posed by urban logistics and the rise of e-commerce. This approach not only addresses environmental concerns, but also improves operational efficiency (Rodríguez-Palero et al., 2024). EVs in the last mile provide improved sustainability by reducing carbon emissions and improving energy efficiency. They integrate technological advances like battery technologies and smart grids, addressing challenges in e-commerce logistics (Cano et al., 2022). EVs are used in the last mile delivery to improve efficiency and reduce negative environmental impact, addressing urban air and noise pollution (Ilin et al., 2023). Successful implementation of EVs requires adapting delivery routes and selecting suitable EVs models to ensure all orders are fulfilled efficiently (Głodowska, 2023). Simulation and experimental methods confirm that with route optimization and vehicle selection, EVs can effectively replace or complement traditional diesel vans in Polish urban areas, such as the Szczecin agglomeration (Wilczarska et al., 2024).

Further researches considering the acceptance of EVs in courier sector and raising awareness considering environmental protection among the Polish society are needed. *The aim of the article is to verify the readiness of e-consumers and the determinants to use an eco-innovative method of last-mile delivery by Electric Vehicles* (*EVs*) *in the courier services*. In particular, the research focuses on answering the following questions:

Do individual technology Readiness of e-consumers measured by optimism and innovativeness influence the EVs adoption for last mile delivery?

Do trust and environmental awareness of e-consumers influence the intention to use last mile delivery by EVs?

What are the mediating roles of perceived ease of use and perceived usefulness in the relationship between optimism, innovativeness, trust, environmental awareness and the Intention to use EVs in last-mile delivery?

Are the internal relationships – specifically, between perceived ease of use, perceived usefulness, and intention to use – validated in the context of EVs adoption for last-mile delivery?

The article begins with a literature review on EVs adoption for last-mile delivery and social acceptance models, followed by a description of the methodology. It then presents empirical findings and concludes with practical implications, study limitations, and future research directions.

2. Literature review

Rising environmental concerns and regulatory requirements have recently compelled the logistics industry to embrace sustainable practices. Eco-innovation, open innovation, and stakeholder pressure drive renewable energy adoption in logistics firms, with managers' cognitive awareness enhancing the impact of innovation on sustainability initiatives (Sadiq et al., 2025). The adoption of eco-innovation such as EVs for last-mile delivery in e-commerce presents both opportunities and challenges. EVs offer significant environmental benefits, reducing greenhouse gas emissions by 17–54% compared to internal combustion engine vehicles (Siragusa et al., 2022). They can also be economically advantageous over an 8-year timeframe, despite higher initial costs (Siragusa et al., 2022). Small businesses show positive attitudes towards EVs adoption, with perceived usefulness and compatibility influencing intention to use (Toraman et al., 2024). However, challenges include fleet size considerations, scheduling, and infrastructure requirements (Anosike et al., 2023). The adoption of electric vehicles is significantly facilitated by the presence of supportive policies and well-developed infrastructure (Zhou et al., 2021). Innovative solutions such as combining EVs with courier service distribution, could further enhance sustainability (Arvidsson, 2010). As e-commerce continues to grow, particularly in fast-moving consumer goods, the integration of EVs in last-mile delivery becomes increasingly important for optimizing operations and addressing environmental concerns (Gulc, 2017; Toraman et al., 2024). In this light, the readiness of e-consumers to implement EVs delivery in last-mile distribution is beneficial.

E-consumer adoption of EVs can be examined using the Technology Acceptance Model (TAM) that has been applied to study in various contexts. For example some research has extended TAM to include additional factors relevant to EVs adoption, such as cultural adaptation for international websites (Singh et al., 2006), perceived green utility and infrastructure readiness for EVs in Brazil (Soares Filho et al., 2024), autonomous buses using powered by electricity (Ejdys et al., 2025), consumer knowledge about EVs directly and indirectly affects adoption intention in an emerging market (Jaiswal et al., 2022), gender (Zhang et al., 2022a) and perceived risk in Indonesia (Salim et al., 2024). In the context of ecological vehicles adoption by users, perceived usefulness and perceived ease of use consistently emerge as central predictors of intention to use, reflecting the Technology Acceptance Model's assertion that users adopt technologies they perceive as effective and simple to operate (Zhou et al., 2021; Zhou & Yi, 2025). Referring to the courier services, in Vietnam, researchers investigated carriers' intentions to use electric cargo vehicles in last-mile delivery, finding that attitude, perceived ease of use, perceived risk, public engagement, and face consciousness influenced adoption (Ngoc et al., 2023).

To better explain consumer adoption of e-services, Lin et al. integrated Technology Readiness (TR) into TAM, creating the TRAM model into the realm of consumers' adoption of innovations (Lin et al., 2007). Moreover, settings of this study is exhibited by consumers' self-determining selection behaviour and their high involvement in the e-service creation and delivery process. As consequence the results indicate that TRAM substantially broadens the applicability and the explanatory power of either of the prior models and may be a better reference point for further considerations.

TR denotes an individual's overall propensity to embrace and effectively employ new technologies in both personal and occupational contexts. Follow by (Parasuraman, 2000) TR represents a comprehensive psychological state shaped by a constellation of cognitive enablers and inhibitors, which collectively influence an individual's predisposition toward the adoption and use of emerging technologies.

As a reference point for the theoretical and practical considerations being conducted, the conceptual model presented in Figure 1 has been adopted. Authors developed it incorporating selected variables of TR proposed by (Lin et al., 2007). Specifically, Optimism and Innovativeness were included as key enablers and drivers of TR in the context of EVs adoption. Optimism reflects a favourable attitude toward technology, characterized by the belief that technology enhances one's control, efficiency, and flexibility in daily tasks. Innovativeness denotes a proclivity to be an early adopter and a leader in exploring new technological solutions. Innovativeness functions as a moderating factor, more innovative individuals are likely to perceive EVs as useful and trustworthy, thereby strengthening adoption intentions, while lower innovativeness may limit this effect (Zhou et al., 2021; Zhou & Yi, 2025).

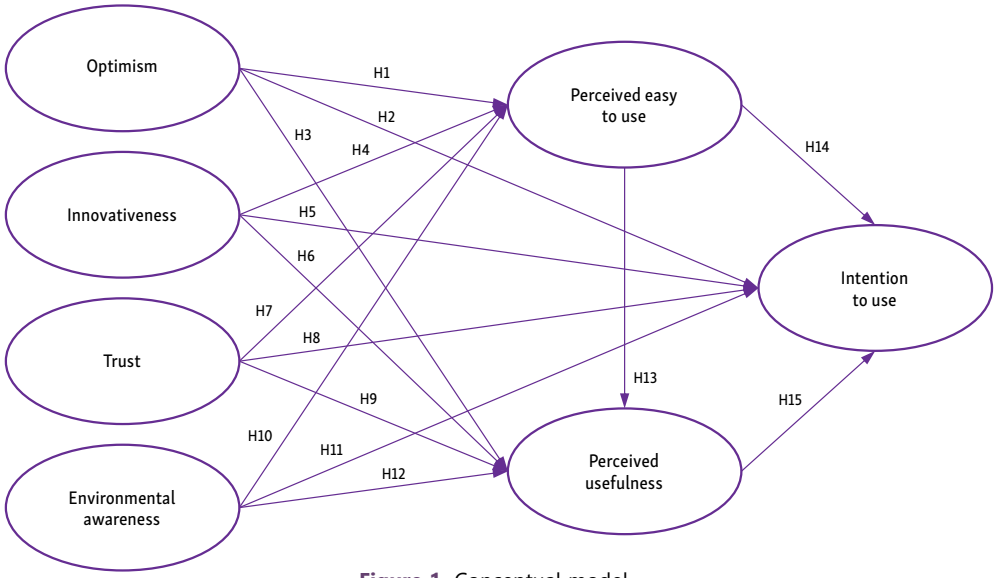

Figure 1. Conceptual model

Conversely, two constructs: Discomfort and Insecurity were deliberately excluded from the analysis. The exclusion of Discomfort was justified by the early stage of EVs market development in the courier last-mile delivery sector, where limited maturity raises concerns about the interpretability and validity of responses. E-consumers in Poland currently lack sufficient experience with EVs-based courier services, further limiting the construct's relevance. The construct Insecurity was conceptually reframed and replaced by trust, reflecting its critical importance in the EV market (Bryła et al., 2023; Zhang et al., 2022b). For EVs, attitude, subjective norms, and perceived trust significantly impact adoption intention (Thakur et al., 2023). Trust in the technology and service provider further mediates the relationship between perceived usefulness and intention to use, enhancing confidence and reducing perceived risk, though its direct effect may vary depending on operational transparency and infrastructure reliability (Zhou et al., 2024; Zhou & Yi, 2025). Additionally, given the study's focus on eco-innovation, the authors incorporated the construct of Environmental Awareness into the model. Among e-consumers it was identified as a vital factor influencing sustainable adoption behaviours, thus warranting its inclusion in the conceptual model. The environmental concerns, perceived usefulness, and incentives positively affect consumer attitudes towards EVs (Alberto & Riza, 2023). Environmental awareness also plays a crucial role, particularly in contexts emphasizing sustainability, as individuals with strong pro-environmental attitudes exhibit higher intention to use by perceiving EV adoption as morally and socially valuable (Zhou et al., 2021, 2025).. While environmental concerns were examined, their direct impact on EVs adoption intentions was not always evident (Soares Filho et al., 2024).

For EVs adoption in last-mile delivery, factors such as Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Intention to Use (ITU) play crucial roles (Ngoc et al., 2023; Toraman et al., 2024). This study proposes the following hypotheses to examine the relationships between individual traits, perceptions, and behavioural intentions in the context of technology adoption:

H1: *Optimism is expected to positively impact PEOU.*

H2: *Optimism is expected to positively impact ITU.*

H3: *Optimism is expected to positively impact PU.*

H4: *Innovativeness is expected to positively impact PEOU.*

H5: *Innovativeness is expected to positively impact ITU.*

H6: *Innovativeness is expected to positively impact PU.*

H7: *Trust is expected to positively impact PEOU.*

H8: *Trust is expected to positively impact ITU.*

H9: *Trust is expected to positively impact PU.*

H10: *Environmental awareness is expected to positively impact PEOU.*

H11: *Environmental awareness is expected to positively impact ITU.*

H12: *Environmental awareness is expected to positively impact PU.*

H13: *PEOU is expected to positively impact PU.*

H14: *PEOU is expected to positively impact ITU.*

H15: *PU is expected to positively impact ITU.*

Even if the TAM and TRAM model has already been examined in various sectors (Kampa, 2023; Kamaruddin et al., 2021; Mahmood et al., 2023) to authors best knowledge there is a gap regarding courier service using EVs for the e-deliveries in the delivery last mile. These studies fill this gap.

3. Data and methodology

The methodology of this study involves a quantitative approach using Structural Equation Modelling (SEM). To collect data a structured questionnaire of nine questions, a metric and filter questions was used. The survey was developed based on the hypotheses formulated in the conceptual model (see Figure 1), ensuring that each construct (presented in Table 2) was represented by validated measurement items. These items were adapted from existing literature and tailored to fit the context of the study to ensure content validity and relevance.

The survey was conducted in April–May 2025, preceded in March 2025 by a pilot study on a sample of randomly selected 20 respondents, using the Computer-Assisted Web Interview (CAWI) technique. In this way authors verified the validity of the questionnaire, both in terms of the clarity of the questions and their substantive consistency. The selection of the final sample was reasonably planned in the context of a proper understanding of the mechanisms of choice of courier services by e-consumers. Therefore, filter questions were used: (1) regarding the age of majority of respondents and therefore legal purchasing power (2) the experience in making at least one transactional online purchase and (3) e-consumers' experience in using courier services. Finally the study involved 743 individuals, of which a total of 698 respondents filled in the questionnaire correctly. The gender distribution was almost proportional (54% female and 45% male). In terms of age, the respondents were mostly young people, under 25 years of age (55%) and middle-aged, i.e., age range 40–55 (23%), with the smallest group being older people, over 70 (1%), likely due to filtering questions. More than half of the respondents live in medium-sized and large cities (mainly central part of Poland), earning above-average salaries. An interesting variable concerns the type of car they own and/or use. The overwhelming majority, over 75% of responses, indicated petrol vehicles.

The more detailed characteristics of the research sample in terms of the main sociodemographic variables are presented in the Table 1.

The study sample was also analysed in terms of the frequency of online shopping, as well as the awareness and fact of using courier delivery options with EVs. The detailed percentages for the group of respondents considered are shown in Table 2.

Further, in-depth analysis of the respondents' metrics allows for other interesting and necessary conclusions to be defined for further analysis. Namely, online buyers predominate among the respondents, declaring their purchasing activity to be at the level of several transactions per month (49.3%). However, the awareness and actual level of use of EVs deliveries remains severely limited. Only 27.5% of respondents said they had noticed such an option on offer from courier companies. An even smaller percentage – 18.6% of respondents – admitted that they had ever used this type of service. These results indicate an important need to analyse the issues addressed and to develop appropriate recommendations to disseminate good practices in the area studied.

Table 1. Characteristics of the research sample

Variables		Percentage (%)
Gender	Female	53.9
	Male	45.4
	Prefer not to answer	0.7
Education	Elementary	0.3
	Vocational	1
	Secondary	47.9
	Higher	50.9
Age	18–25	55.3
	26–39	10.7
	40–55	24.9
	56–70	7.6
	71+	1.4
Dwelling place	Village	21.3
	City up to 50,000 inhabitants	9.9
	City from 50,000–150,000 inhabitants	8.6
	City from 150,000–500,000	26.8
	City with more than 500,000 inhabitants	33.4
Average net monthly income per household member	Less than 2000 PLN	8.6
	2000–3500 PLN	24.9
	3501–5000 PLN	31.2
	More than 5000 PLN	35.2
Type of car owned or used	Petrol	76.4
	Hybrid	7.3
	Electric	0.7
	n/a	15.6

Table 2. Characteristics of the research sample

Variables		Percentage (%)
Frequency of online shopping	Every day or several times a day	1.4
	2–3 times a week	11.3
	Once a week	13.2
	Several times a month	49.3
	Several times a year	23.5
	1–2 times a year and rarely	1.3
Awareness of courier delivery by EV possibilities	Yes	27.5
	No	72.5
Experience in using courier delivery by EVs	Yes	18.6
	No	81.4

The data obtained was statistically verified, using CAF (Confirmatory Factor Analysis) and MLE (Maximum Likelihood Estimation) methods. Each identified construct of Table 3 was measured using validated items adapted from established literature.

Table 3. The list of constructs and their variables in the conceptual model

Construct	Variables
Optimism	A1: Technologies give people more control over their daily lives.
	A2: Products and services that use the latest technology are much more convenient to use.
	A3: I prefer to use the most advanced technology available.
	A4: Technologies provide greater mobility.
Innovativeness	Inn1: Other people come to me for advice on new technologies.
	Inn2: I'm one of the first friends in my circle to use new technologies as soon as they come out.
	Inn3: I;m up to date with the latest technological developments in my areas of interest.
	Inn4: I like the challenge of inventing high-tech gadgets.
	Inn5: I am always open to learning about new and different technologies.
Trust	T1: I believe courier services are reliable.
	T2: I believe that courier companies are honest with customers about delivery.
	T3: I believe that courier companies take proper care of their customers.
	T4: I believe that courier companies are characterized by high credibility.
Environmental awareness	EA1: I am aware of the impact of traditional deliveries (internal combustion vehicles) on air pollution.
	EA2: I am aware that electric vehicles generate lower CO_2 emissions compared to internal combustion vehicles.
	EA3: I try to choose deliveries that have a lower negative impact on the environment.
	EA4: I believe that my decision on the form of delivery can contribute to the protection of the environment.
	EA5: I pay attention to how the delivery of my order is processed.
	EA6: I believe that companies should offer environmentally friendly delivery options, e.g., with electric vehicles.
	EA7: I feel responsible for supporting environmental activities through my daily choices.
	EA8: I appreciate companies that invest in green forms of transport, even if the delivery takes a little longer.
	EA9: I'd love to pay a bit more for an eco-friendly delivery.
Perceived usefulness	PU1: I believe that the use of electric vehicles for deliveries improves the company's image as a modern and socially responsible company.
	PU2: Electric deliveries are just as fast and reliable as those made with internal combustion vehicles.
	PU3: I feel more responsible when I know that my order is delivered by an electric vehicle.
	PU4: In my opinion, the use of electric vehicles has a positive impact on the natural environment.
	PU5: I believe that deliveries made by electric vehicles are the future of courier deliveries.

The above items were modified to align with the specific context of the study, thereby ensuring content validity and contextual relevance. The data obtained was then statistically verified in relation to the hypotheses posed by the conceptual model (Figure 1).

4. Results

In order to verify the measurement relevance, multivariate statistical procedure Confirmatory Factor Analysis (CFA) was carried out for each of the tested constructs separately. The obtained values of the fit indices indicate a good or very good fit of the models to the empirical data, presented in Table 4.

Table 4. Average values, standard deviations and reliability measures of the constructs tested

Contruct &variables		M	SD	Factor loading	Cronbach's alpha	CR	AVE
Optimism	O1	5.32	1.495	0.717	0.831	0.838	0.567
	O2	5.63	1.256	0.869			
	O3	5.04	1.428	0.710			
	O4	5.82	1.158	0.703			
Innovativeness	Inn1	3.99	1.613	0.682	0.829	0.831	0.552
	Inn2	3.19	1.550	0.789			
	Inn3	4.26	1.608	0.756			
	Inn4	3.54	1.725	0.742			
Trust	T1	4.04	1.649	0.648	0.853	0.865	0.619
	T2	4.62	1.394	0.793			
	T3	4.54	1.267	0.851			
	T4	4.48	1.258	0.838			
Environmental awareness	EA3	3.78	1.702	0.747	0.896	0.897	0.593
	EA4	4.22	1.660	0.787			
	EA6	4.57	1.610	0.688			
	EA7	4.47	1.689	0.812			
	EA8	4.33	1.698	0.845			
	EA9	3.13	1.773	0.732			
Perceived usefulness	PU1	4.63	1.685	0.757	0.873	0.873	0.581
	PU2	4.62	1.426	0.624			
	PU3	3.59	1.643	0.782			
	PU4	4.26	1.696	0.824			
	PU5	4.31	1.686	0.808			

A perfect fit was obtained for the construct Optimism (χ^2/df = 0.19; RMSEA = 0.000; SRMR = 0.004; CFI = 1.000; TLI = 1.005), while Innovativeness (χ^2/df=2.45; RMSEA = 0.046; CFI = 0.997; TLI = 0.991) and Trust (χ^2/df = 2.37; RMSEA = 0.044; CFI = 0.998; TLI = 0.994) values were also within the recommended limits. The constructs Environmental Awareness and PU also achieved acceptable fit indices (RMSEA = 0.078 and 0.043, respectively), with high values for the relative indices (CFI ≥ 0.987; TLI ≥ 0.973). All latent variables analysed had

high internal consistency, as evidenced by Cronbach's alpha coefficient values ranging from 0.829 to 0.896. Composite Reliability (CR) exceeded the recommended threshold of 0.70 for all constructs, while average explained variance (AVE) achieved values above 0.50, meeting the criterion for convergent validity (Fornell & Larcker, 1981).

All factor loadings were statistically significant and exceeded the value of 0.60. The items of the tested constructs with low values were reduced (for Innovativeness-Inn5, for the construct Environmental Awareness – EA1, EA2 and EA5). In addition, error correlations were added between EA3 and EA4 and between EA6 and EA8 – the rationale for this decision is the wording of these items, which could be understood very similarly. The above results confirm that all constructs show an acceptable level of measurement validity and can be included in the full structural model.

The construct PEOU (Cronbach's alpha = 0.762) contained 4 items where the item loadings of PEOU3 and PEOU4 were less than 0.5, after reducing one of the items to re-run the CFA analysis the model proved to be unidentifiable due to the number of degrees of freedom df = 0. In the case of the ITU construct (Cronbach's alpha = 0.874), the number of degrees of freedom was also df = 0, and it was therefore decided that validation would be performed with the full SEM model. A similar procedure was also followed in the literature, as reported by (Guo et al., 2009).

In order to empirically verify the research hypotheses, a full structural model was estimated using the Maximum Likelihood Estimation (MLE) method, presented in Figure 2. The full SEM (Structural Equation Modelling model showed a satisfactory fit to the empirical data, as evidenced by the values of the key fit assessment indicators. The value of the chi-square statistic was significant (χ^2 = 1033.74; df = 332; $p < 0.001$), but the ratio of the chi-square value to the number of degrees of freedom was 3.114, which is within the acceptable range for models with moderate fit. The fit indices also confirm the validity of the model. The CFI and IFI values reached 0.938, the TLI was 0.930 and the NFI-0.912, all exceeding the minimum threshold of acceptability of 0.90, while approaching the level of a very good fit (≥0.95) (Hu & Bentler, 1999). In addition, the RMSEA value was 0.055, indicating a very good fit of the model to the data obtained. The confidence interval for the RMSEA ranged from 0.051 to 0.059 and the p-value was 0.014, indicating that the model does not meet the strict criterion of RMSEA ≤ 0.05 at the 0.05 significance level, but is still close to this limit. The parsimony indices also support the relevance of the model, with PRATIO, PNFI and PCFI values of 0.878, 0.801 and 0.824, respectively, confirming that the model combines high quality fit with moderate structural complexity. The adequacy of the model is also confirmed by the value of the Hoelter index, which was 254 (for a significance level of 0.05) and 267 (for a level of 0.01). These values are above the threshold of 200, indicating a sufficient sample size to reliably assess the fit of the model. The results obtained confirm a proper fit for the structural model.

The reliability and convergent validity of each of the constructs analysed were reassessed in the full structural model. All constructs met the recommendations of (Fornell & Larcker, 1981) with CR values ranging from 0.754 to 0.894, thus exceeding the threshold of 0.70, indicating high measurement reliability. The AVE values for all latent variables ranged from 0.553 to 0.692, so they exceeded the recommended threshold of 0.50, indicating a satisfactory level of convergent validity. The construct ITU obtained CR = 0.871 and AVE = 0.692, while the

construct PEOU obtained CR = 0.754 and AVE = 0.605. All factor loadings had values higher than 0.6. The exception to this was the construct PEOU, which, due to low factor loadings, was reduced to two items and ultimately only PEOU1 and PEOU2 were present in the structure. According to (Bollen & Davis, 2009), latent constructs measured by two indicators are theoretically acceptable in an SEM model as long as the model is identifiable through the relationships between the constructs. These results confirm that all latent variables in the model have adequate measurement properties to enable reliable and accurate assessment of the relationships within the structural model. The results of the model testing are presented in Table 5.

The above results of the self-analysis, indicate that Optimism significantly, positively influences PEOU (β = 0.269; p < 0.001), PU (β = 0.080; p = 0.013) and negatively influences ITU (β = –0.098; p = 0.005). The constructs Innovativeness and Trust showed no significant association with any of the dependent variables (p > 0.05). In contrast, Environmental Awareness showed a strong significant effect on PEOU (β = 0.678; p < 0.001) and PU (β = 0.516; p < 0.001), but its direct association with ITU was found to be statistically insignificant (p > 0.05). All hypotheses regarding the internal relationships between the key components of the TAM model were further confirmed. PEOU positively affects both PU (β = 0.493; p < 0.001) and ITU (β = 0.425; p < 0.001). In contrast, PU significantly influences ITU (β = 0.422; p = 0.001), which is in line with classical TAM assumptions. And PEOU positively affects both PU (β = 0.493; p < 0.001) and ITU (β = 0.425; p < 0.001). In contrast, PU significantly influences ITU (β = 0.422; p = 0.001), which is in line with classical TAM assumptions.

Table 5. The results of model testing

H	Statistical relationship	Standardized estimate	Unstandardized Estimate	S.E.	C.R.	p	Decision
H1	Optimism->PEOU	0.269	0.298	0.049	6.059	<0.001	Accepted
H2	Optimism->ITU	–0.098	–0.112	0.040	–2.814	0.005	Accepted
H3	Optimism->PU	0.080	0.094	0.038	2.488	0.013	Accepted
H4	Innovativeness->PEOU	0.005	0.005	0.046	0.117	0.907	Rejected
H5	Innovativeness->ITU	0.042	0.046	0.034	1.373	0.170	Rejected
H6	Innovativeness->PU	–0.018	–0.020	0.033	–0.622	0.534	Rejected
H7	Trust->PEOU	0.070	0.079	0.042	1.881	0.060	Rejected
H8	Trust->ITU	–0.013	–0.015	0.031	–0.489	0.625	Rejected
H9	Trust->PU	0.003	0.004	0.030	0.138	0.890	Rejected
H10	Environmental Awareness-> PEOU	0.678	0.610	0.040	15.106	<0.001	Accepted
H11	Environmental Awareness-> ITU	0.114	0.106	0.069	1.530	0.126	Rejected
H12	Environmental Awareness->PU	0.516	0.494	0.047	10.591	<0.001	Accepted
H13	PEOU->PU	0.493	0.524	0.058	9.023	<0.001	Accepted
H14	PEOU->ITU	0.425	0.437	0.096	4.535	<0.001	Accepted
H15	PU->ITU	0.422	0.409	0.125	3.273	0.001	Accepted

Table 6. Direct, indirect and total effects of the indicated relationships

Relation	Indirect effects	Direct effects	Total effects
Optimism->PEOU->ITU	0.114**	–0.098**	0.106*
Optimism->PU->ITU	0.034**	–0.098*	0.106*
Environmental Awareness->PEOU->ITU	0.288**	0.114**	0.761
Environmental Awareness->PU->ITU	0.218**	0.114**	0.761
PEOU->PU->ITU	0.208*	0.425**	0.633**

Note: * p < 0.05; **p < 0.01; ***p < 0.,001.

The next step analysed whether mediating effects were present in the model under study. The results are presented in Table 6.

In the case of the relationship Optimism→Intention to Use, both the indirect path through PEOU (β = 0.114; p < 0.01) and through PU (β = 0.034; p < 0.01) were statistically significant. The direct effects had a negative direction (β = –0.098; p < 0.05 and p < 0.01, respectively) and the total effect was positive (β = 0.106; p < 0.05). This indicates the presence of partial mediation, in which the positive effect of optimism on ITU is revealed only through the components of the TAM model. For the relationship Environmental Awareness→ITU, both the path through PU (β = 0.218; p < 0.01) and through PEOU (β = 0.288; p < 0.01) were significant. Direct effects also reached significance (β = 0.114; p < 0.01), while the total effect was no longer statistically significant (β = 0.761; p = 0.169). This configuration of effects, in which the overall effect loses significance when mediators are taken into account, indicates the presence of full mediation, in which the entire effect of the independent variable on the outcome variable is transmitted through mediating variables. In contrast, in the relationship PEOU→ITU, mediation by PU was included. The indirect effect reached β = 0.208 and was significant (p < 0.05), while the direct effect remained strong and significant (β = 0.425; p < 0.01), indicating partial mediation, consistent with the assumptions of the classical TAM model.

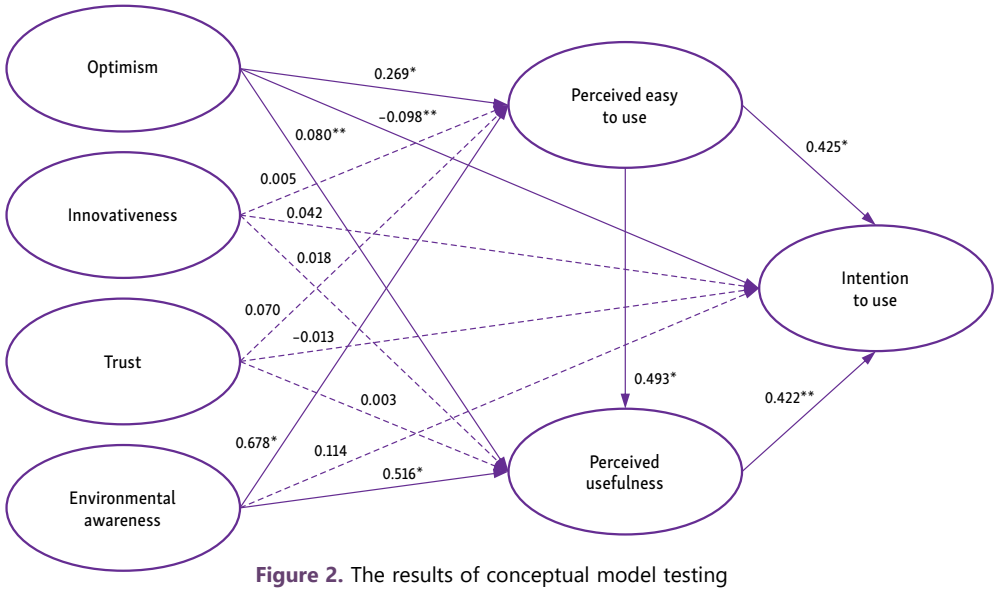

Figure 2. The results of conceptual model testing

5. Discussion and implications

The findings of this study provide insights into social acceptance of EVs in last mile delivery by examining the relations between Optimism, Innovativeness, Trust, Environmental Awareness, Perceived Ease of Use, Usefulness and future Intentions to Use deliveries served by EVs in courier services.

The obtained results revealed that Perceived Ease of Use positively influences both Perceived Usefulness and Intention to use EVs in last mile delivery, which is consistent with the assumptions of the classic TAM model and well-supported by recent research. Studies indicate that PEOU significantly enhances PU, which in turn positively influences the intention to adopt EVs for delivery purposes (Ngoc et al., 2023; Toraman et al., 2024). Consistent with the Technology Acceptance Model, PEOU and PU emerged as significant mediators, transmitting the effects of distal psychological and attitudinal determinants, including optimism and environmental awareness, into behavioural intention (Durmus Senyapar et al., 2023; Jaiswal et al., 2021; Kousar et al., 2025; Ngoc et al., 2022; Shalender, 2024). This reinforces the established notion that functional evaluations of system performance and usability are the primary drivers of adoption. A user-friendly interface and experience with EVs can enhance consumer confidence and willingness to use them for last-mile delivery (Yick & Selamat, 2024). Customers are more likely to adopt EVs if they believe these vehicles are easy to operate and integrate into existing logistics systems (Msosa, 2023). Therefore, innovations in battery technology and smart grids enhance the usability of EVs, making them more appealing for last-mile delivery (Mogire et al., 2025). Studies highlight that consumers are more likely to adopt EVs when they perceive them as beneficial for their delivery needs (Saleh et al., 2024). Perceived usefulness is identified as a critical factor in the acceptance of EVs, as it relates to the efficiency and environmental benefits of using EVs (Ambak et al., 2016; Saravanos et al., 2022). The findings suggest that stakeholders should implement educational initiatives to improve consumer perceptions of EVs, focusing on ease of use and usefulness (Hussain & Qureshi, 2024).

The results indicate that Optimism positively influences Perceived Ease of Use, Perceived Usefulness and negatively influences Intention To Use. Although, the direct effect of Optimism on Intention to Use had a negative direction, but the total effect through mediators (Perceived Ease of Use and Perceived Usefulness) was positive. This indicates the presence of partial mediation, in which the positive effect of optimism on intention to use is only revealed through the components of the TAM model. These results align with prior observations that optimism about technology exerts mixed and context-dependent direct influences on adoption behaviour (Koppel et al., 2024). A positive outlook towards EVs can enhance the perceived ease of use, making carriers more likely to adopt them (Ngoc et al., 2023). Optimistic views about the efficiency and sustainability of EVs contribute to their perceived usefulness, further influencing acceptance (Msosa, 2023). Innovations in battery technology and charging infrastructure can foster optimism, enhancing the perceived ease of use of EVs (Mogire et al., 2025). In practical EV delivery contexts, optimistic expectations may enhance perceptions of usefulness and usability but are insufficient to directly translate into adoption intentions, likely due to operational or cost-related constraints.

The constructs of Innovativeness and Trust have been shown to lack a significant association with Perceived Ease Of Use, Perceived Usefulness, and Intention to Use EVs in last-mile

delivery. Innovativeness, which prior studies identify as a positive predictor of adoption and a moderator of trust and PU (Hasan et al., 2024; Shalender, 2024), showed no significant direct or indirect effects in this study. This divergence may reflect market maturity and technological familiarity, whereby individual differences in openness to novelty exert less influence. Furthermore, organizational or infrastructural factors may constrain adoption, reducing the observable impact of personal innovativeness. Although innovativeness often facilitates adoption by enhancing perceptions of usefulness and trust, these pathways were not statistically significant in the present context. This finding is not clearly supported by various studies that explore user acceptance of innovative solutions and delivery technologies in logistics. Innovativeness has been linked to Perceived Ease Of Use in some contexts, such as delivery applications, where higher innovativeness correlates with a perception of ease (Kim & Lee, 2017). Innovativeness in EVs technology enhances perceived usefulness, leading to higher acceptance rates among users (Shanmugavel et al., 2022). On the contrary, personal innovativeness does not directly influence purchase intention of EVs but can affect it indirectly through attitudes and perceived risks (Maso & Balqiah, 2022). Similarly, trust did not demonstrate significant direct or indirect effects on ITU, contrasting with previous findings that highlight trust as a key mediator in the PU–ITU relationship (Bryła et al., 2023; Rezvani et al., 2015; Shalender, 2024). This may be explained by a baseline assumption of service reliability in established delivery systems, which diminishes variability in trust perceptions. Additionally, standardized operational procedures, regulatory compliance, and consistent service performance may reduce the functional necessity of trust as a predictor, rendering it less salient in influencing adoption intentions. In the context of last-mile delivery, trust mitigates perceived risks associated with new technologies, thereby enhancing user confidence and intention to adopt EVs (Chalermpong et al., 2024). Similarly, attitude, subjective norms, and perceived trust significantly impact adoption intention of EVs (Thakur et al., 2023). However, while trust is a critical factor in technology acceptance, studies indicate that it may not significantly impact perceived usefulness or ease of use in the case of EVs (Sakuljao et al., 2023).

Environmental Awareness, on the other hand, shows a strong, significant impact on Perceived Ease of Use and Perceived Usefulness of last mile delivery by EVs, which is in line with with prior research demonstrating the importance of pro-environmental attitudes in shaping adoption behavior (Kousar et al., 2025; Shanmugavel & Balakrishnan, 2023; Vyasha, 2025; Wu et al., 2019). Full mediation suggests that environmental concern motivates adoption primarily by enhancing perceptions of system usefulness and ease of use rather than directly influencing behavioural intention. This finding underscores the importance of translating value-based attitudes into actionable behaviour through functional evaluations. Studies show that the perceived environmental benefits of EVs contribute positively to their perceived usefulness, particularly in urban logistics (Wu et al., 2019). Environmental Awareness mediates the relationship between attitudes and purchase intentions for EVs, suggesting that higher awareness leads to greater perceived usefulness (Phoon et al., 2023). Similarly, environmental concern has been linked to increased acceptance of EVs, which correlates with perceived ease of use. Consumers are more likely to view EVs as user-friendly when they recognize their environmental benefits (Wu et al., 2019). According to the study results, the relationship between environmental awareness and intention to use EVs in last mile delivery was found to be statistically insignificant. This finding suggests that while environmental awareness is often

considered a critical factor in promoting sustainable practices, it may not directly influence the decision to adopt EVs for last-mile delivery. According to previous studies, environmental concern and perceived green vehicle knowledge do not directly translate into the intention to switch to EVs, as consumption values like epistemic and social values are more influential in shaping attitudes (Le, 2024). Consumers are increasingly highlighting concerns regarding the recyclability of Electric Vehicle (EV) batteries, thereby sending a clear signal to industry stakeholders to prioritize the development of solutions that align with the principles of a circular economy.

In summary, while PEOU and PU remain central to adoption, distal psychological and attitudinal factors such as optimism, innovativeness, trust, and environmental awareness, exert effects primarily through cognitive mediators. Contrasts with prior studies can be attributed to contextual factors including market maturity, operational constraints, baseline service reliability, and consumer familiarity with EV delivery systems. These results highlight the continued relevance of TAM constructs while illustrating that the predictive power of personality traits and generalized trust may diminish in operationalized service contexts. Based on the empirical findings, several implications for the adoption of EVs in last-mile delivery can be drawn. First, the results indicate that customers' openness to innovation and trust in technology or providers do not exhibit a significant influence on their intention to adopt EVs for last-mile delivery. This suggests that marketing strategies emphasizing the innovative character of EVs or the reliability of manufacturers may be insufficient or even unnecessary for encouraging adoption in this context. Accordingly, stakeholders should critically evaluate the effectiveness of allocating resources to such promotional approaches. Second, while customers with heightened environmental awareness perceive EVs as both more useful and easier to use, this awareness does not directly translate into a stronger intention to adopt. This implies that although environmental values shape perceptions, they are insufficient in isolation to drive behavioural change. To transform environmental concern into concrete adoption behaviour, it is crucial that EV solutions are perceived as not only environmentally beneficial but also functionally advantageous and operationally straightforward. Third, environmental concern alone does not consistently lead to adoption behaviour, particularly when other contextual barriers like cost, limited driving range, insufficient infrastructure are present. Therefore, for EVs adoption initiatives in last-mile delivery to succeed, environmental messaging must be accompanied by practical, operational enhancements that address the real-world constraints faced by end users. Fourth, although optimism toward technology can exert a positive influence on adoption intentions, this effect emerges primarily through indirect pathways – namely, via perceptions of ease of use and usefulness. Notably, the direct effect of optimism on intention is negative, which may reflect overly optimistic or unrealistic expectations that are not matched by actual experience. This underlines the importance of transparent communication by decision-makers, who should ensure that positive user dispositions are grounded in accurate, evidence-based representations of EVs performance and integration feasibility. Finally, the core constructs of the Technology Acceptance Model remain highly pertinent. Perceived ease of use significantly influences both perceived usefulness and intention to use, while perceived usefulness has a direct and substantial impact on the intention to adopt. These findings confirm that customers

are more likely to favour EVs when the vehicles are perceived as user-friendly and capable of enhancing delivery performance or reducing operational costs. Therefore, design and implementation efforts should emphasize intuitive usability and demonstrable efficiency gains. Tu sum up, for EVs adoption initiatives in last-mile delivery to succeed, environmental messaging must be accompanied by practical, operational enhancements that address the real-world constraints faced by end users. Overall, these findings highlight the importance of aligning technological, environmental, and usability factors to effectively drive behavioural change in the adoption of EVs in last mile delivery.

6. Conclusions

6.1. Theoretical contributions

The findings confirm that Perceived Ease of Use and Perceived Usefulness remain central predictors of behavioral intention, reinforcing TRAM's robustness in explaining technology-driven behavioral change in logistics. However, the study also reveals that optimism influences adoption indirectly through these perceptions, while innovativeness and trust show no significant effects – challenging assumptions common in the innovation diffusion literature. Furthermore, the non-significant direct impact of environmental awareness on adoption intention highlights the need to link environmental values with tangible functional advantages, suggesting an important theoretical refinement for sustainability-related TRAM applications.

6.2. Practical contributions

The study offers actionable insights for logistics firms, policymakers, and technology providers. To accelerate EV adoption in last-mile logistics, stakeholders should focus not only on environmental messaging but also on improving the usability and operational efficiency of electric fleets. Governments can play a central role in accelerating EV adoption in last-mile delivery through coordinated measures aligned with national transport strategies such as Polish *Strategy for Sustainable Transport Development by 2030*. Key priorities should include investment in public charging networks for commercial fleets, tax relief or subsidies for zero-emission logistics operators, and the introduction of low-emission delivery zones in urban areas. Local authorities could integrate EV deployment into sustainable mobility plans, offering preferential access or reduced tolls for electric fleets. For logistics companies, industry collaboration through shared charging infrastructure, battery lifecycle management, and partnerships with municipalities will be crucial to reduce costs and ensure operational continuity. Joint public-private initiatives can enhance fleet electrification and foster innovation, supporting the transition toward carbon-neutral urban logistics systems. Logistics companies should also promote EVs as practical and cost-efficient rather than merely sustainable, integrating them with user education programs and transparent communication about performance limitations. Moreover, aligning EV initiatives with circular economy principles – such as battery recycling and sustainable supply chains – can amplify both environmental and social benefits, including emissions reduction and consumer awareness.

6.3. Limitations and future research

This study's cross-sectional design limits causal inference and prevents observation of behavioral evolution over time. Future longitudinal research could track changes in consumer acceptance as technology matures, and infrastructure improves. Additionally, the regional scope restricts the generalizability of findings; comparative studies across different markets or cultures are encouraged. Future research should also explore cost-related and policy variables, as well as the influence of emerging technologies – such as autonomous delivery vehicles or smart routing systems – on EV adoption. Mixed-method approaches, combining surveys with qualitative interviews, may yield deeper insights into perceived risks, usability challenges, and communication strategies that foster realistic expectations toward EV integration in logistics.

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Author contributions

The authors collaborated on every part of the article.

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