Jurnal Ekonomi dan Bisnis, Vol. 13 No. 4 Desember 2024
P - ISSN : 2503-4413
E - ISSN : 2654-5837, Hal 538 – 553

Multi-Stakeholder Framework for Analyzing Electric Vehicle Adoption in Last-Mile Delivery Fleets: A Literature-Based Approach for Computational Modeling in Indonesia

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Article Info
Article History :
Received 25 Jul - 2024
Accepted 03 Oct - 2024
Available Online
15 Dec – 2024

Abstract
Indonesia is experiencing an accelerated transition towards widespread electric vehicle (EV) adoption, bolstered by governmental support aimed at mitigating greenhouse gas emissions. While extensive research has been conducted on public acceptance of EVs, there remains a significant gap in the literature regarding the logistics sector, particularly in the domain of last-mile delivery. This gap is becoming increasingly salient as the e-commerce industry continues to expand, amplifying the impact of this sector. This study aims to provide a more comprehensive perspective on EV adoption by logistics firms by incorporating multiple stakeholders: the logistics firm itself, government entities, receivers, and suppliers. The research develops a multifaceted framework for EV adoption that encompasses these four stakeholder groups, with a particular emphasis on the logistics firm. This firm-centric approach is further delineated into two distinct levels: managerial and end-user (i.e., couriers). The proposed framework is designed to be implemented within computational modeling paradigms, facilitating deeper insights into how various factors surrounding logistics firm operations influence the electrification of last-mile delivery processes. This approach allows for a more nuanced understanding of the intricate relationships and interactions between stakeholders and operational variables in the context of EV adoption within the logistics sector.

***Keyword** : Computational Modelling, last-mile delivery, electric vehicle, logistics, sustainability*

1. INTRODUCTION

In Indonesia, transportation sector is the second largest CO2 emitter (24.71%) after energy production sector (47.81%). This equates to 127,881 Gg CO2e. The number is increasing by average of 6.69% each year from 2007 to 2016 (Kementerian ESDM Republik Indonesia, 2017). Moreover, Southeast Asian Nations have commited to build the most-fuel efficient vehicle market into the world by 2025 as a form of supporting the ASEAN Economic Community 2025 vision (ASEAN Secretariat, 2019). Electrification of the logistic system is one of the steps that must be taken to reach that goal. Logistical routes are divided into several parts, and each utilizes different kind of vehicles for increased efficiency (Kin et al., 2018). In this research writers focus on last- mile delivery as it is among the most energy consuming logistics *operations in the supply chain because of the vast amount of stops and low fill rates (Halldórsson & Wehner, 2020).*

In Indonesia, last-mile delivery operations are predominantly carried out by motorcycles. Last-mile delivery refers to the final step in the delivery process, where goods are transported from a distribution hub to their final destination, typically a customer's home or business. This stage is crucial in the supply chain as it directly impacts customer satisfaction and operational efficiency. The country's relatively high but evenly distributed population density, narrow streets, and uniformly distributed road network make motorcycles a practical choice for point-to-point travel in many urban areas (Guerra, 2019). Consequently, motorcycles have become the primary vehicle for logistics companies' last-mile delivery operations. However, the extensive use of internal combustion engines in motorcycles emits substances harmful to both human health and the environment, particularly in residential areas (Huu et al., 2021). Research indicates that electric two-wheelers produce significantly lower pollution per kilometer compared to traditional motorcycles and cars (Ji et al., 2018). Furthermore, battery prices are declining at an annual rate of 13% to 17% (Ziegler & Trancik, 2021), suggesting that the barriers to fleet electrification are lower than ever from a business perspective (Davis & Figliozzi, 2013).

In support of this transition, the Indonesian government has ratified President Regulation Number 55 of 2019, which has become the framework for subsequent regulations that increase financial and non-financial incentives to accelerate the mass adoption of battery electric vehicles (BEVs). This regulatory change has been well-received by vehicle manufacturers, as evidenced by the increased local production and release of BEV models since the regulation's implementation, as illustrated in Figure 1.

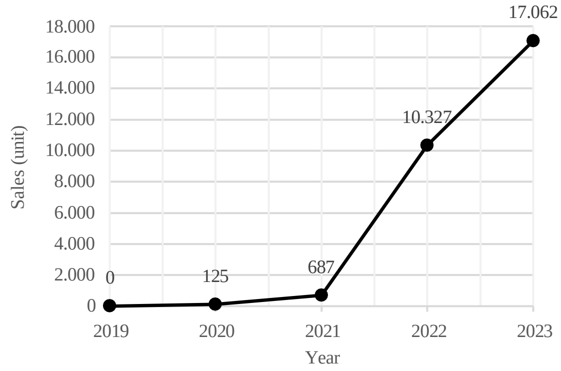

Figure 1. *Yearly BEV sales numbers in Indonesia*

Source: 2019-2023 GAIKINDO Car Wholesales Data

Previous research has consistently demonstrated that government policy support serves as big driver to the adoption of EV (Chandra et al., 2010; Khazaei & Tareq, 2021; Huang, 2021; Wang, 2021). This finding highlights the importance of governmental initiatives in shaping the EV landscape.

Concurrently, Indonesia has witnessed exponential growth in its e-commerce sector over recent years. This expansion can be attributed, in part, to the country's rapidly increasing internet penetration rate, which reached 73.7% in 2020. The number increased significantly compared to 2019 which was only 64.8 % (Wahyudi and Prihatin, 2022). The growth is followed by the shift of market share from B2B (Business to Business) to B2C (Business to Customer). This shift is characterized by "smaller order size, increased daily volumes, small parcel shipments, and same-day shipments" (Joong-Kun Cho et al., 2008, p.337). The evolving e-commerce landscape has led to a significant increase in last-mile delivery operations. As a result, there is a growing demand for vehicles to fulfill these expanded delivery requirements. This trend presents both challenges and opportunities for the logistics sector, particularly in the context of sustainable transportation solutions such as EVs.

Extensive research has been conducted on the adoption of electric commercial vehicles in urban logistics fleets (Lee et al., 2013; Ziegler & Trancik, 2021; Carrese et al., 2021; Jaller et al., 2021). Similarly, there is a growing body of literature exploring the *general acceptance of battery electric vehicles (BEVs) in Indonesia (Guerra et al., 2019; Murtiningrum et al., 2022; Kusharsanto et al., 2024). However, there remians a notable gap in research regarding BEV adoption by Indonesian logistics companies, particularly in last-mile delivery scenarios. This study aims to address this gap by developing a comprehensive framework for BEV adoption geared towards Indonesian logistics companies, incorporating perspectives from multiple relevant stakeholders.*

The study of product adoption and usage intention has been enriched by numerous theoretical frameworks, with the Theory of Planned Behavior (TPB) and its derivatives emerging as prominent models. These theoretical foundations form the basis of the present research in examining stakeholder behavior. The stakeholder classification employed in this study aligns with the work of Taniguchi et al. (2001), which posits four primary stakeholders in urban logistics scenarios: suppliers (manufacturers, wholesalers, and retailers), carriers (transporters, warehouses, and companies), receivers (typically residents), and administrators (at national, state, and city levels).

The integration of these theoretical frameworks into computational models has been a recurring theme in urban logistics and last-mile delivery research. For instance, Anand et al. (2014) developed a multi-agent system to model urban freight transportation, while Tamagawa et al. (2010) expanded upon the stakeholder framework to construct an agent-based model for evaluating city logistics regulations.

The present study aims to examine EV adoption factors for each stakeholder through a comprehensive literature review. The result is the development of a framework for electrification of last-mile delivery, grounded in the previously mentioned theories and with a particular emphasis on shipper stakeholders. This model is designed to be integrated into a computational model, facilitating a deeper understanding of the complex dynamics involved in EV adoption within the last-mile delivery sector in Indonesia.

2. LITERATURE REVIEW

2.1. Urban Logistics

Urban logistics is defined as that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and point of consumption to meet customers' requirements, as influenced by complex interactions among densely populated social systems and associated infrastructure (Rose et al., 2017). One of the big parts in urban logistics is last-mile delivery. It is defined as "a series of activities and processes that are necessary for the delivery process from the last transit point to the final drop point of the delivery chain" (Yuen et al., 2018). In this scenario, commercial vehicles that operate in an urban environment spend a significant portion of their trip time in idlle (Lee et al., 2013). However, even though the scope looks narrow, multiple stakeholders take part in decision making of urban logistics domain. The decision-making processes between the stakeholders change according to the situation. Therefore, to properly study the system, complex interaction between the stakeholders must be considered (Anand et al., 2016). There are four main stakeholders in logistics (Taniguchi, 2001):

- *Administrator: includes authorities at local, regional, or national (or even international) level that can influence urban goods movements (traffic authorities, infrastructure authorities, municipalities, and railway terminal/port authorities). Road users and residents are not directly involved in city logistics activities; however, their objectives align with those of the administrator and thus we assume that they are being represented by administrators.*
- *Supplier: includes stakeholders who supply commodity or service (producers, wholesalers, intermediate retailers, and traders)*
- *Carrier: includes stakeholders connected with activities of distribution of goods (delivery firms, third-party logistics, forwarders, and drivers)*
- *Receiver: includes stakeholders who receive goods or service (shopkeepers,*

restaurants, office, house, and individuals).

Based on study by Anand (2015) each stakeholder has their own objectives in city logistics.

***Table 1:** city logistics stakeholders and objectives*

Stakeholder	Objective
Administrator	• Accessibility • Governance and legislation • Negative environmental impact reduction • Liveability • Goods availability
Suppliers	• Market growth • Profitability
Carriers	• Congestion • Cost effectiveness, minimum use of resources
Receivers	• Competitiveness • Profitability • On-time delivery

2.2. New Technology Adoption in Organization

The adoption of new technologies by organizations has been a focal point of research across multiple disciplines, including information systems, management, and organizational behavior. Scholars have investigated this phenomenon from various angles, spanning individual-level acceptance (Baker, 2012; Li, 2020; Bae et al., 2022) to organization-wide implementation strategies (Tornatzky and Fleischer, 1990; Baker, 2012; Katebi et al., 2022).

Several theories have emerged to explain individual technology adoption, many of which build upon the Theory of Planned Behavior (TPB). TPB examines how attitudes, subjective norms, and perceived behavioral control influence intentions and actions (Ajzen, 1985). Subsequent models have further developed our understanding of technology adoption behavior. The Technology Acceptance Model (TAM), for instance, proposes that perceived ease of use and perceived usefulness mediate the relationship between system characteristics and actual system use (Davis, 1989).

Advancements in this field include the Unified Theory of Acceptance and Use of Technology (UTAUT), which analyzes the effects of performance expectancy, effort expectancy, social influence, and facilitating conditions on technology acceptance (Venkatesh et al., 2003). The UTAUT2 model, an extension designed for consumer contexts, incorporates additional factors such as hedonic motivation, price value, and habit, while considering individual differences as potential moderators of these effects on behavioral intention and technology use (Venkatesh et al., 2012).

Recent academic discourse has highlighted the importance of perceived risk in understanding the complexity of new technology adoption. Several studies have integrated this concept with TPB to offer a more comprehensive framework for analyzing adoption behaviors (Raut & Kumar, 2024; Wang et al., 2022; Xie et al., 2017; Gunawan et al., 2022).

While these theories effectively explain individual technology adoption, it's important to note that in organizational contexts, end-users of technologies often lack the choice to accept or reject such adoptions (Ahmad et al., 2012). Consequently, researchers have developed frameworks specifically tailored to organizational settings. A notable example is the Technology-Organization-Environment (TOE) framework, developed by Tornatzky and Fleischer (1990), which provides a comprehensive approach to understanding technology adoption at the organizational level.

2.3. Computational Modelling

In the pursuit of simulating and studying complex systems, such as the adoption of new technologies, researchers have employed various computational modeling techniques that surpass the capabilities of simple analytical models. These advanced methods enable the exploration of the dynamics and interactions that would otherwise be challenging to capture. This paper examines three prominent computational modeling approaches: statistical modeling, system dynamics (SD), and agent-based modeling (ABM). Each of these methodologies offers unique advantages in elucidating the multifaceted nature of complex systems and providing insights into their behavior and evolution.

Statistical modeling techniques, particularly structural equation modeling (SEM), have been widely employed to analyze the complex relationships between variables in various phenomena, including the adoption of EVs. SEM's ability to simultaneously examine multiple interdependent relationships has made it a valuable tool in exploring the determinants of EV adoption *across diverse scenarios. For instance, Gunawan et al. (2022) utilized SEM to investigate the factors influencing EV adoption in Indonesia, employing an integrated theoretical framework. Their study analyzed data collected through surveys distributed across various Indonesian cities, enabling the identification of key drivers of EV adoption interest. Similarly, Khazei et al. (2021) applied SEM to explore the primary promoting factors and barriers to BEV adoption in Kuala Lumpur, Malaysia. These studies exemplify the efficacy of SEM in uncovering the multifaceted dynamics of EV adoption, providing valuable insights for both researchers and policymakers in the field of sustainable transportation.*

SD is used to understand and analyze complex systems' behavior over time. It addresses systems characterized by interdependence, mutual interaction, information feedback, and circular causality. SD has proven particularly valuable in studying policy implications across various domains. For example, Rahmawati et al. (2023) employed SD to investigate the dynamic behavior of Taiwan's EV market in response to policy interventions. Their model incorporated a range of factors, including consumer preferences, financial acceptability, and charging infrastructure accessibility, providing a nuanced analysis of the system's behavior. In a similar vein, Gao et al. (2024) applied SD to examine how fueling infrastructure funding policies affect the medium- to long-term diffusion of BEVs and fuel cell electric vehicles (FCEVs). By integrating relevant policy and market data, their model evaluated the effectiveness of various funding strategies for fueling infrastructure development.

These studies highlight ability of SD to shed light on complex interactions within socio-technical systems and its usefulness in informing policy decisions in sustainable transportation. By simulating different scenarios and policy options, SD allows researchers and policymakers to gain insights that might be difficult to obtain through other methods.

ABM is a computational method employed to simulate the actions and interactions of autonomous agents within a defined environment. This approach is particularly valuable for studying complex systems where the behavior of the whole emerges from the individual decisions and interactions of its constituent parts. ABM has been extensively utilized to model the diffusion of new technologies, as it can simulate diverse behaviors within a given population. For instance, Sopha et al. (2017) employed ABM to compare non-psychological and psychological models of consumer adoption decision-making, investigating the diffusion of natural gas vehicles (NGV) in Indonesia under various incentive policy scenarios. Similarly, Huang et al. (2021) applied this method to study consumer behavior and evaluate policy interventions aimed at driving higher electric vehicle (EV) adoption rates in China by influencing consumer decision-making.

A critical aspect of these modeling methods is the determination of key factors prior to model development. These factors are typically identified through rigorous literature review, empirical evidence, or well-established theoretical frameworks. This preliminary step ensures that the model accurately reflects the complex dynamics of the system under study and provides meaningful insights into the diffusion of new technologies.

3. RESEARCH METHOD

To address the previously mentioned research questions, a literature review on related topics was conducted. A literature review can be broadly described as a systematic method of collecting and synthesizing previous research (Baumeister and Leary, 1997; Tranfield et al., 2003). An effective and well-conducted review, as a research method, creates a firm foundation for advancing knowledge and facilitating theory development. By integrating findings and perspectives from numerous empirical studies, a literature review can address research questions with greater power than any single study (Snyder, 2019). For this review, Elsevier (www.sciencedirect.com) was primarily used as the literature source.

4. ADOPTION FRAMEWORK

This research draws primarily upon the city logistics stakeholder model proposed by Taniguchi et al. (2001) to develop a framework for firm-level EV adoption. The *original model comprises four key stakeholders: administrators, suppliers, carriers, and receivers. However, to better reflect the contemporary conditions of last-mile delivery, this study extends the original framework by considering receivers not only as clients but also as residents. In this context, the term "resident" encompasses other road users who may interact with delivery routes.*

4.1 Firm perspective on BEV adoption (Carriers)

Within a firm, technology adoption typically occurs at two distinct levels: managerial and end-user. Depending on the organizational structure, end-users often lack the autonomy to adopt or reject new technologies, as these decisions are predominantly made at the managerial level. In the context of last-mile delivery, the end-users are typically courier drivers. However, notable exceptions exist, such as Grab and Gojek, two prominent transportation and delivery service providers in Indonesia. These companies afford their partnered drivers the freedom to adopt electric motorcycles (EMs) by providing the vehicles and offering financial schemes to fund EM usage. Consequently, this study will examine adoption from both managerial and end-user perspectives.

4.1.1 Managerial level

At the managerial level, decision-making encompasses company-wide policies. Stakeholders at this echelon must maintain a holistic perspective on the matter, which differs significantly from individual adoption processes. The Technology-Organization-Environment (TOE) framework, as described by Baker (2012), offers a comprehensive approach to analyzing organizational adoption of new technologies by considering technological, organizational, and external factors.

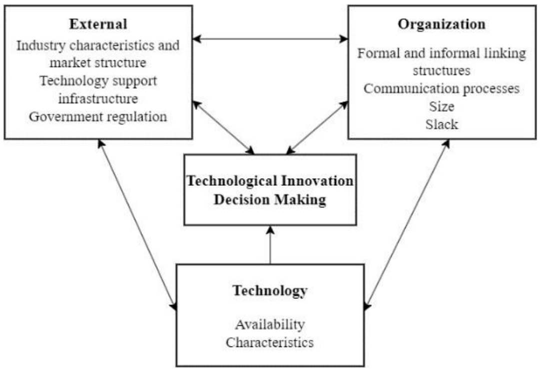

Figure 2. *TOE framework*
Source: Baker, 2012

These factors are broken down further into financial, organizational, technical, environmental, regulatory, and social factors to fit into the current context. Relevant aspects of each of these factors are then identified through literature review.

Financial factors play a crucial role in the decision-making process. Operational costs and acquisition costs are primary considerations, as they directly impact the company's financial performance (Sierzchula, 2014; Comi and Savchenko, 2021; Bae et al., 2022; Xie et al., 2022; Avenali et al., 2023, 2024). Financial incentive policies also significantly influence EV adoption, as they can offset initial high costs and make the transition more economically viable (Alali et al., 2022; Bae et al., 2022).

Organizational factors encompass several aspects. The company's culture, particularly its perception of sustainability and green brand image, can be a driving force for EV adoption (Strawderman et al., 2022; Avenali et al., 2024). Knowledge and training within the organization regarding EV usage are essential for successful implementation (Sierzchula, 2014; Widya-Hasuti et al., 2018; Mohammed et al., 2020). Deployment strategies and organizational structure, specifically the degree of autonomy given to couriers in vehicle selection, can impact the rate of EV adoption (Baker, 2012; Widya-Hasuti et al., 2019; Mohammed et al., 2020). Management's sustainable attitude (Wolff and Madlener, 2019; Baah et al., 2020; Xie et al., 2022) and technophilia - their receptiveness to new technologies (Strawderman et al., 2022; Avenali et al., 2024) - are also critical organizational factors. Strategic gain, or the potential competitive advantages from EV adoption, is another important consideration

(Sierzchula, 2014; Mohammed et al., 2020; Xie et al., 2022).

Technical considerations are paramount in EV adoption. Vehicle operation, including factors such as route planning, operating speed, and range, must be carefully evaluated (Mohammed et al., 2020; Comi and Savchenko, 2021; Avenali et al., 2024). Technological risks associated with EV drawbacks and their potential impact on operations (operational risks) need to be assessed (Baker, 2012; Wolff and Madlener, 2019; Bae et al., 2022; Khan and Maoh, 2022). Vehicle performance, including EV specifications and operational capabilities, is another crucial technical aspect (Baker 2012; Wolff and Madlener, 2019; Bae et al., 2022).

Environmental factors are increasingly important in the current business landscape. The potential for lowering wheel-to-wheel emissions and reducing noise pollution are significant motivators for EV adoption (Sierzchula, 2014; Bae et al., 2022; Avenali et al., 2024).

Regulatory factors, such as emission restriction policies imposed by governments, can compel companies to consider EVs as a means of compliance (Baker, 2012; Sierzchula, 2014; Maghfiroh et al., 2021; Achmad et al., 2023). Non-financial incentives also play a role in promoting EV adoption (Baker, 2012; Maghfiroh et al., 2021).

Social factors also influence managerial decision-making regarding EV adoption. Social signaling, or the pressure from society to adopt environmentally friendly practices, can influence company changes (Gong et al., 2019; Baah et al., 2020; Mohammed et al., 2020; Sierzchula, 2020). The potential enhancement of the company's environmental image through EV adoption is another consideration (Gong et al., 2019; Mohammed et al., 2021; Xie et al., 2022). Subjective norms, or the perceived social pressure to engage in certain behaviors, can also affect a company's operations and decisions regarding EV adoption (Wolff and Madlener, 2019; Strawderman et al., 2022; Mohammed et al., 2022).

***Table 2:** Literature review of managerial-level adoption factors and aspects.*

Factors	**Aspects**	**Referecences**	**Explanations**
Financial	Operational cost	Sierzchula, 2014; Comi and Savchenko, 2021; Bae et al., 2022; Xie et al., 2022; Avenali et al., 2023	Evaluation of vehicle operational expenses
	Acquisition cost	Sierzchula, 2014; Comi and Savchenko, 2021; Alali et al., 2022; Avenali et al., 2024	Analysis of vehicle purchase expenses
	Financial Incentive policies	Sierzchula, 2014; Alali et al., 2022; Bae et al., 2022; Avenali et al., 2024	Impact of financial incentives on company operations
Organizational	Culture	Strawderman et al., 2022; Avenali et al., 2024	Assessment of managerial and company perceptions regarding sustainability and green brand image
	Knowledge and training	Sierzchula, 2014; Widya-Hasuti et al., 2018; Mohammed et al., 2020; Avenali et al., 2024	Evaluation of existing EV knowledge and training provision within the company
	Deployment Strategies and Organizational structure	Baker, 2012; Widya-Hasuti et al., 2019; Mohammed et al., 2020;	Measurement of courier autonomy in EV versus ICEV selection
	Sustainable attitude	Wolff and Madlener, 2019; Mohammed et al., 2020; Baah et al., 2020; Xie et al., 2022	Evaluation of management's perception of sustainability benefits for the company
	Technophilia	Wolff and Madlener, 2019; Mohammed et al., 2020; Strawderman et al., 2022; Avenali et al., 2024;	Assessment of management's openness to new technology adoption
	Strategic gain	Sierzchula, 2014; Mohammed et al., 2020; Xie et al., 2022	Examination of potential competitive advantages from EV adoption
Technical	Vehicle operation	Mohammed et al., 2020; Comi and Savchenko, 2021; Avenali et al., 2024	Analysis of vehicle operational factors including routes, speed, and range
	Technological Risk	Baker, 2012; Wolff and Madlener, 2019; Mohammed et al., 2020; Bae et al., 2022; Khan and Maoh, 2022; Avenali et al., 2024	Evaluation of potential risks associated with EV technological limitations
	Operational Risk	Mohammed et al., 2020; Wolff and Madlener, 2019; Bae et al., 2022; Khan and Maoh, 2022; Avenali et al., 2024	Assessment of operational impacts due to EV technological drawbacks
	Vehicle performance	Baker 2012; Wolff and Madlener, 2019; Mohammed et al., 2020; Bae et al., 2022; Avenali et al., 2024;	Analysis of EV specifications and operational capabilities
Environmental	Lowering wheel-to-wheel emissions	Sierzchula, 2014; Bae et al., 2022; Avenali et al., 2024	Measurement of company's focus on reducing greenhouse gas emissions

	Noise pollution reduction	*Sierzchula, 2014; Bae et al., 2022; Avenali et al., 2024*	*Evaluation of company's emphasis on minimizing noise emissions*
Regulatory	*Emission Restriction Policy*	*Baker, 2012; Sierzchula, 2014; Maghfiroh et al., 2021; Bae et al., 2022; Achmad et al., 2023*	*Assessment of governmental environmental regulations' impact on operations*
	Non-Financial incentives	*Baker, 2012; Maghfiroh et al., 2021; Sierzchula, 2014*	*Examination of non-monetary factors promoting EV adoption*
Social	*Social signalling*	*Gong et al., 2019; Gong et al., 2019; Baah et al., 2020; Mohammed et al., 2020; Sierzchula, 2020*	*Analysis of social pressure's influence on company changes*
	Environmental image	*Gong et al., 2019; Baah et al., 2020; Sierzchula, 2020; Mohammed et al., 2021; Xie et al., 2022*	*Evaluation of the significance of environmental reputation for the company*
	Subjective norm	*Wolff and Madlener, 2019; Strawderman et al., 2022; Mohammed et al., 2022*	*Assessment of social norms' influence on company operations*

4.1.2 End-user level

This study approaches the adoption process for end-users, particularly courier drivers, through the lens of established individual adoption models such as the TPB, TAM, and UTAUT. To maintain focus and relevance, the model incorporates only factors specific to the last-mile delivery context, allowing for a targeted examination of technology adoption by courier drivers while drawing on well-established theoretical foundations. The determinants for EV adoption by courier drivers are categorized into five main factors: cost, technical, personal, external, and sustainability. Each of these factors is further broken down into detailed aspects to fit the current context, mirroring the approach used at the managerial level.

Cost factors are often crucial in adoption considerations. The acquisition price of EVs is a significant determinant, as highlighted by several studies (Guerra, 2019; Wang et al., 2020; Huu and Ngoc, 2021; Choi et al., 2022; Gao et al., 2024). Operating costs also play a vital role in the adoption decision (Choi et al., 2022; Maghfiroh et al., 2021; Amedokpo, 2024; Dianita et al., 2025). Financial incentive policies can significantly influence EV adoption by offsetting initial high costs and operational expenses (Huu and Ngoc, 2021; Gunawan et al., 2022).

Technical factors are equally crucial in the EV adoption process. The driving range of EVs is a critical consideration (Guerra, 2019; Neves et al., 2019; Gao et al., 2024), as is charging time (Huu and Ngoc, 2021; Choi et al., 2022). The availability of charging infrastructure also plays a crucial role in adoption decisions (Guerra, 2019; Maghfiroh et al., 2021). Other technical aspects include comfort (Neves et al., 2019; Kusharsanto et al., 2024), speed (Guerra, 2019; Amedokpo, 2024), and safety features (Pasaoglu et al., 2016; Gunawan et al., 2022).

Personal factors, such as individual perceptions of EV use, significantly influence adoption choices (Mohammed et al., 2020; Khazei and Tareq, 2021; Lee et al., 2021). Performance expectancy, or the anticipated performance of EVs, also affects adoption decisions (Mohammed et al., 2020; Gunawan et al., 2022).

***Table 3:** Literature review of end user level adoption factors and aspects.*

Factors	***Aspects***	***Referecences***	***Explanations***
Cost	*Acquisition price*	*Guerra, 2019; Wang et al., 2020; Huu and Ngoc, 2021; Maghfiroh et al., 2021; Gunawan et al., 2022; Choi et al., 2022; Gao et al., 2024*	*Assessment of EV purchase costs*
	Operating cost	*Choi et al., 2022; Huu and Ngoc, 2021; Maghfiroh et al., 2021; Gunawan et al., 2022; Amedokpo, 2024; Dianita et al., 2025*	*Evaluation of EV operational expenses*
	Financial Incentive policies	*Choi et al., 2022; Huu and Ngoc, 2021; Maghfiroh et al., 2021; Gunawan et al., 2022; Amedokpo, 2024; Dianita et al., 2025*	*Impact of financial incentives on adoption decisions*
Technical	*Range*	*Guerra, 2019; Neves et al., 2019; Gunawan et al., 2022; Choi et al., 2022; Gao et al., 2024; Dianita ert al., 2025*	*Influence of EV driving range on adoption decisions*
	Charging time	*Guerra, 2019; Huu and Ngoc, 2021; Maghfiroh et al., 2021; Choi et al., 2022; Gao et al., 2024*	*Effect of EV charging duration on adoption choices*
	Infrastructure availability	*Guerra, 2019; Huu and Ngoc, 2021; Maghfiroh et al., 2021; Choi et al., 2022; Gao et al., 2024*	*Impact of EV charging infrastructure accessibility on adoption*
	Comfort	*Neves et al., 2019; Amedokpo, 2024; Kusharsanto et al., 2024; Budiman et al., 2024; Dianita et al., 2025*	*Influence of EV driving comfort on adoption decisions*
	Speed	*Guerra, 2019; Neves et al., 2019; Gunawan et al., 2022; Amedokpo, 2024; Dianita et al., 2025*	*Effect of EV performance speed on adoption choices*
	Safety	*Pasaoglu et al, 2016; Neves et al., 2019; Maghfiroh et al., 2021; Gunawan et al., 2022; Dianita et al., 2025*	*Impact of EV safety features on adoption decisions*

Personal	Perception on EV use	Mohammed et al., 2020; Khazei and Tareq., 2021; Maghfiroh et al., 2021; Lee et al., 2021; Gunawan et al., 2022	Influence of individual perceptions about EVs on adoption
	Performance expectancy	Mohammed et al., 2020; Khazei and Tareq., 2021; Lee et al., 2021; Gunawan et al., 2022	Effect of anticipated EV performance on adoption decisions
External	Organizational support	Wang et al., Li, 2020; Katebi et al., 2022; Amedokpo, 2024	Impact of company support for EV adoption on driver decisions
	Social influence	Mohammed et al., 2020; Lopez et al., 2020; Gunawan et al., 2022; Kusharsanto et al., 2024	Effect of social norms and peer attitudes on EV adoption choices
	Non-Financial incentive policies	Huu and Ngoc, 2021; Maghfiroh et al., 2021; Kusharsanto et al., 2024	Influence of non-monetary incentives on adoption decisions
Sustainability	Environmental concern	Guerra et al., 2019; Neves et al., 2019; Lopez et al., 2020; Khazei and Tareq., 2021; Choi et al., 2022	Impact of individual environmental awareness on EV adoption choices

4.2 External factors

In addition to the carrier companies, this study recognizes three other key stakeholders in the EV adoption process: administrators, suppliers, and receivers. For the purpose of this research, these stakeholders are consolidated into external factors that influence a company's EV adoption process.

The aspects of these external factors are determined by characteristics specific to each stakeholder group. This approach allows for a more comprehensive understanding of the external pressures and influences on EV adoption while maintaining a focused and manageable research framework.

Suppliers, who provide goods for delivery, consider several factors when choosing courier companies that use EVs. The sustainable image of a company is a significant consideration (Yadav and Swaroop, 2016; Sreen et al., 2018; Zhang et al., 2018), reflecting the growing importance of corporate sustainability. Financial and time costs associated with EV use are also crucial factors (Anand et al., 2012; Sanz and Meyer, 2024), as suppliers evaluate the economic implications of their logistics choices. Timeliness, or the punctuality of deliveries, is another key consideration (Taniguchi et al., 2005; Anand et al., 2012; Sanz and Meyer, 2025), as it directly impacts customer satisfaction and supply chain efficiency.

Administrators, typically representing governmental or regulatory bodies, have a different set of considerations. Public demand plays a significant role in shaping policies and regulations (Taniguchi et al., 2005; Anand et al., 2012; Duurling, 2020), as administrators respond to societal pressures for sustainable urban logistics. Political will and commitment to sustainable transition are crucial factors (Avenali et al., 2024), indicating the government's readiness to support EV adoption. Economic motives (Duurling, 2020) and environmental commitments (Anand et al., 2012) also influence administrative decisions, reflecting the dual goals of economic growth and environmental protection.

Receivers, including both businesses and individual customers, have the most diverse set of considerations. Road safety is a primary concern (Karaaslan et al., 2018; Maghfiroh et al., 2021), as the introduction of EVs may alter traffic dynamics. Shipping price (Roorda et al., 2010; Śwircz and Racz, 2021), timeliness (Macário et al., 2008; Śwircz and Racz, 2021; Duurling, 2020), and order completion time (Śwircz and Racz, 2021) are critical factors that directly impact customer satisfaction and choice of carrier. Service reliability is another crucial consideration (Ejdys and Gulc, 2020; German et al., 2022), as it affects the overall quality of the delivery experience.

Environmental concern is an increasingly important factor for receivers (German et al., 2022), reflecting growing public awareness of sustainability issues. Financial and time costs associated with EV-based deliveries are also considered (Roorda et al., 2010; Macário et al., 2008; Sanz and Meyer, 2024), as customers weigh the potential trade-offs between sustainability and convenience. Lastly, the social dimension (Avenali et al., 2024) plays a role, as social pressures and norms influence individual and business decisions regarding the use of EV-based delivery services.

***Table 4:** Literature review of external stakeholder EV adoption support factors.*

Stakeholder	Factors	Referecences	Explanations
Suppliers	Sustainable image	Yadav and Swaroop, 2016; Sreen et al., 2018; Zhang et al., 208	Evaluation of the importance of maintaining a sustainable corporate image
	Financial cost	Anand et al., 2012; Sanz and Meyer, 2024	Assessment of the financial impact of EV adoption on operations

	Time cost	*Taniguchi et al., 2005; Anand et al., 2012; Sanz and Meyer, 2024*	*Analysis of how EV use affects delivery time efficiency*
	Timeliness	*Taniguchi et al., 2005; Anand et al., 2012; Sanz and Meyer, 2025*	*Examination of EV impact on delivery punctuality*
Administrator	*Public demand*	*Taniguchi et al., 2005; Anand et al., 2012; Duurling, 2020*	*Assessment of public criticism and suggestions regarding current and future road use*
	Political will and commitment	*Avenali et al., 2024*	*Evaluation of government willingness to support sustainable transition*
	Economic motives	*Duurling, 2020*	*Analysis of economic incentives driving government support for sustainability*
	Environmental motives	*Anand et al., 2012*	*Examination of government environmental commitments influencing sustainable decisions*
Receivers	*Road safety*	*Karaaslan et al., 2018; Maghfiroh et al., 2021*	*Assessment of potential safety implications of EV adoption*
	Shipping price	*Roorda et al., 2010; Śwircz and Racz, 2021*	*Evaluation of how shipping costs influence customer choice of EV-using carriers*
	Timeliness	*Macário et al., 2008; Śwircz and Racz, 2021; Duurling, 2020*	*Analysis of punctuality's impact on customer selection of EV-using carriers*
	Order completion time	*Śwircz and Racz, 2021*	*Examination of order fulfillment duration's influence on customer choice of EV-using carriers*
	Reliability	*Ejdys and Gulc, 2020;German et al., 2022*	*Assessment of service reliability's role in customer decision-making for EV-using carriers*
	Environmental concern	*German et al., 2022*	*Evaluation of environmental awareness impact on customer selection of EV-using carriers*
	Financial cost	*Roorda et al., 2010Sanz and Meyer, 2024*	*Analysis of potential financial implications for customers using EV-based delivery services*
	Time cost	*Macário et al., 2008;Sanz and Meyer, 2024*	*Examination of time-related impacts on customers using EV-based delivery services*
	Social dimension	*Avenali et al., 2024*	*Assessment of social pressure's influence on customer choice of EV-using carriers*

4.3 Proposed framework

The proposed framework for electric vehicle (EV) adoption in last-mile delivery presents a holistic model that integrates multiple stakeholders and factors across two primary domains: the public domain and the firm domain. This comprehensive approach aligns with the complex nature of urban logistics systems, as highlighted in previous research (Taniguchi et al., 2001; Anand et al., 2012).

In the public domain, the framework identifies three key stakeholder groups: Suppliers, Receivers, and Administrators. This structure reflects the interconnected nature of urban logistics ecosystems (Macário et al., 2008; Duurling, 2020).

Suppliers' decision-making processes regarding EV adoption are influenced by factors such as sustainable image, financial cost, and time cost. These considerations align with recent studies on corporate sustainability and supply chain management (Yadav and Swaroop, 2016; Sreen et al., 2018).

Receivers, representing end customers, evaluate EV acceptance based on road safety, financial implications, timeliness, time costs, and environmental concerns. This multifaceted approach to consumer decision-making echoes findings from recent logistics and consumer behavior research (Śwircz and Racz, 2021; German et al., 2022). Administrators, typically representing governmental bodies, are driven by public demand, political will, economic motives, and environmental considerations. Their role in promoting EV regulations underscores the critical influence of policy in shaping sustainable urban logistics (Avenali et al., 2024).

The firm domain is divided into Managerial and End-user levels, reflecting the dual decision-making processes within organizations. At the Managerial level, the framework identifies six interconnected factors influencing EV adoption and support: Organizational, Environmental, Social, Regulatory, Technical, and Financial. This multidimensional approach aligns with contemporary organizational theory and technology adoption models (Baker, 2012; Mohammed et al., 2020). The End-user level, representing courier drivers, considers Personal, Sustainability, Organizational, Social, Technical, and Cost factors in their EV adoption decisions.

This granular approach to individual adoption behaviors builds upon established theories such as the TAM and the TPB (Wolff and Madlener, 2019; Khazei and Tareq, 2021). The framework illustrates interactions between these domains and levels, highlighting the interdependencies in urban logistics systems. For instance, administrator regulations influence both public stakeholders and firm-level decisions, while supplier and receiver behaviors in the public domain affect firm-level strategies. This interconnectedness echoes recent research on the systemic nature of urban logistics innovations (Comi and Savchenko, 2021; Bae et al., 2022).

The framework's delineation of factors across different domains and levels enables modelers to capture the interdependencies between stakeholders, potentially leading to more accurate predictions of adoption patterns and policy impacts. This computational application of the framework

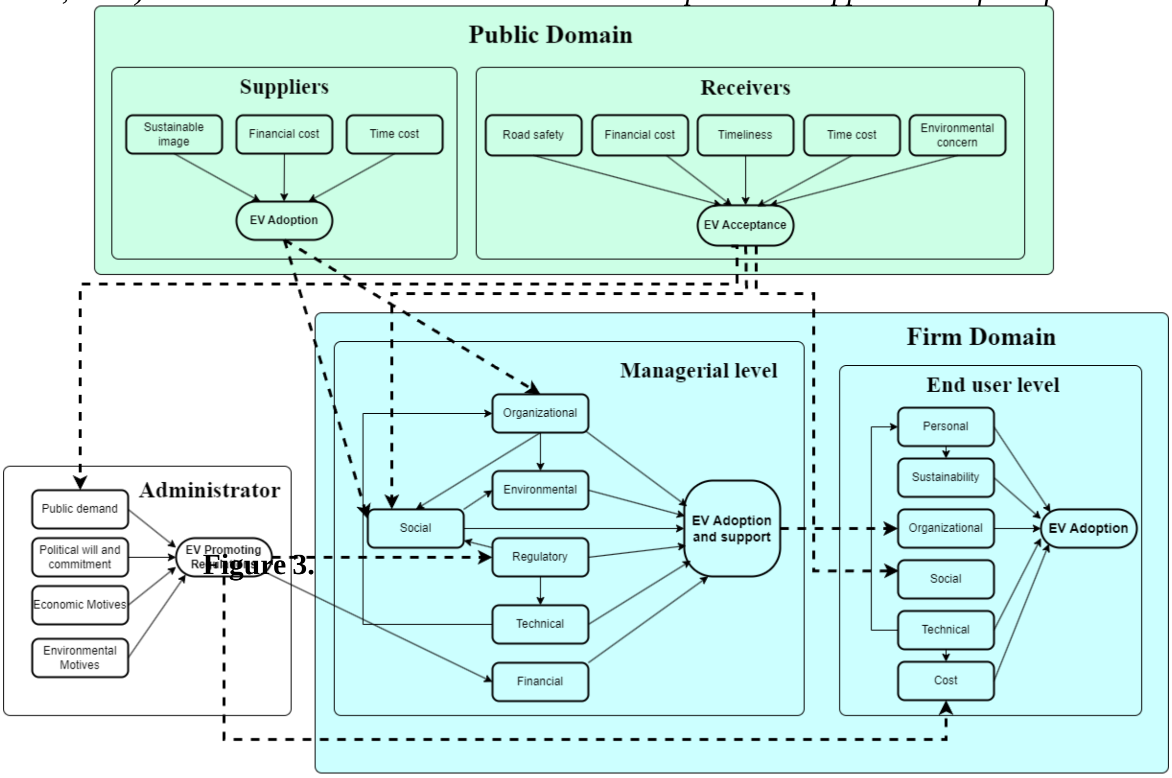

Figure 3.

5. *CONCLUSION*

In conclusion, this framework provides a structured approach to analyzing the multifaceted challenges and opportunities in transitioning to EV-based last-mile delivery systems. By integrating diverse stakeholder perspectives and considering a wide range of factors, it offers a comprehensive tool for researchers and policymakers to address the complexities of sustainable urban logistics.

Moreover, this framework is specifically designed to facilitate computational modeling of EV adoption in last-mile delivery. By clearly establishing the key factors that need to be considered for each stakeholder group, it provides a solid foundation for developing quantitative models. These factors can be operationalized as variables in agent-based models, system dynamics simulations, or other computational approaches, allowing for a more rigorous and systematic analysis of the interactions and dynamics within the EV adoption ecosystem.

can aid in scenario planning, policy evaluation, and strategic decision-making for sustainable urban logistics.

Future research could focus on empirically validating this framework, exploring its applicability across different urban contexts and scales, and developing specific computational models based on the identified factors and relationships. Such efforts would contribute to a more nuanced understanding of EV adoption in last-mile delivery and support evidence-based strategies for promoting sustainable urban logistics.

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