**An Investigation into the Major Barriers to the Adoption of Electric Vehicles in Last Mile Deliveries for Sustainable Transport**

***Abstract***

**Purpose –** Although electric vehicles (EVs) offer promising solutions for reducing transport emissions, several obstacles hinder their adoption, and supply chain stakeholders must systematically identify and address these challenges. Prior research has explored barriers to EV adoption but lacks a global focus on last-mile delivery. Our study aims to fill this gap, providing a foundation for future research and aiding organizational shifts towards sustainable transportation.

**Design/methodology/approach -** Our study identifies 21 critical barriers to EV deployment in last-mile deliveries, validated through a quantitative survey involving 157 supply chain experts. The survey data is analysed using Exploratory Factor Analysis (EFA), which identifies four distinct dimensions encapsulating the identified barriers. Based on consultations with five experts, the Analytical Hierarchy Process (AHP) ranks these dimensions and individual impediments globally.

**Findings -** The study finds 'Energy and Infrastructure Barriers' and 'Financial and Resource Barriers' to be the most significant hindrances. Noteworthy individual barriers include the absence of fast charging stations, insufficient electricity provision, and the need for investment in power grid upgrades.

**Originality -** This research contributes to the existing literature by offering a robust methodology for classifying and ranking EV adoption barriers through EFA and AHP. It thus provides a globally applicable framework for stakeholders to devise targeted strategies for overcoming these barriers.

**Key Words**: Last mile deliveries; electric vehicles; sustainable freight transportation; barriers; AHP; EFA; logistics; green; supply chain.

**1. Introduction**

E-commerce's meteoric rise has transformed logistical frameworks, profoundly altering supply chain management, transportation networks, warehousing paradigms, and last-mile delivery (LMD) systems. Experts predict that the global e-commerce arena will eclipse $6.5 trillion by 2023 (“Global e-commerce sales growth (2023–2027) [Aug 2023 update],” n.d.). This growth and escalating delivery vehicle numbers exacerbate congestion and environmental issues (Ha *et al.*, 2023). Consequently, LMDs transportation externalities have intensified (Patella *et al.*, 2020).

Drawing from the research by Kumar *et al.* (2022) and the sustainability principles outlined by the World Commission on Environment and Development (WCED), it becomes evident that Sustainable Freight Transport (SFT) in Last-Mile Deliveries (LMDs) emerges as an ecologically prudent approach to concluding the delivery process. It harmoniously reduces environmental footprints, curtails energy consumption, and accentuates efficiency, ensuring timely fulfilment of consumer needs. Modern enterprises face challenges in meeting the growing demand for rapid delivery and the expectation of product convenience and affordability (De La Torre *et al.*, 2021).

The logistics sector stands at the forefront of a transformational era, gravitating towards SFT practices that balance environmental conservation, fiscal efficiency, and social inclusivity. The cornerstone of this shift rests on adopting sustainable methodologies, enlightened policy directives, and innovative technologies. Consequently, logistics entities confront the urgency of recalibrating their strategies, emphasizing integrated sustainable transport protocols. However, although the gravitation toward green systems like Electric Vehicles (EVs) is promising, it presents intricate challenges that necessitate adept navigation (Carter *et al.*, 2019).

Recent literature comprehensively addresses the diverse and complex barriers to adopting electric vehicles (EVs), highlighting critical infrastructural, technological, and market-related challenges. Central to these discussions is recognising significant infrastructural and policy constraints magnified by geographic and market variability, necessitating targeted interventions to mitigate these barriers (Aungkulanon *et al.*, 2023). Further compounding these challenges is integrating renewable energy sources and developing sustainable industrial practices, such as efficient battery recycling, essential for supporting a transition to sustainable mobility (D’Adamo, Gastaldi and Ozturk, 2023).

Moreover, the literature suggests that economic considerations are crucial, with studies indicating that EVs offer substantial cost and emission reductions in densely populated urban settings where traditional delivery methods are less effective (Pahwa and Jaller, 2022). Innovative logistics models that utilize e-vans and e-cargo bikes, optimized through advanced routing algorithms, have been proposed as practical strategies to address the complexities of urban delivery systems (Caggiani *et al.*, 2021). Additionally, consumer preferences for EV charging infrastructure emphasize the importance of accessible and well-located charging solutions to facilitate the adoption of EVs (Hardman *et al.*, 2018).

The body of literature emphasizes a comprehensive approach, integrating both technological innovations and socio-economic strategies, to enhance the integration of EVs into LMD systems. This synthesis is crucial for aligning with broader sustainability goals while adapting to the specific geographic and market conditions encountered across various regions. The research underscores the need for strategic frameworks that effectively address the vast array of barriers to EV adoption, calling for robust policies that support the scalability of these vehicles in diverse urban landscapes (Biresselioglu *et al.*, 2018; Kuppusamy *et al.*, 2017; Morganti and Browne, 2018). In-depth studies specific to regions such as the UK, Brazil, India, and Malaysia offer valuable insights into local regulatory and socio-demographic factors that can influence EV adoption, thereby providing a richer understanding of how sustainable freight transport can be implemented within the logistics sector (Asadi *et al.*, 2022; Goel *et al.*, 2021; de Mello Bandeira *et al.*, 2019; Morganti and Browne, 2018; Tarei *et al.*, 2021). These studies not only probe the unique challenges faced in different locales but also highlight the global nature of the shift towards sustainable mobility, illustrating the critical need for an integrated, multi-faceted approach in the adoption of EVs for last-mile deliveries (de Mello Bandeira *et al.*, 2019; Rosales-Tristancho *et al.*, 2022).

The surge in EVs for LMDs heralds a transformative approach to reducing the environmental footprint of urban freight systems. While existing research predominantly concentrates on generic barriers to EV adoption (D’Adamo, Gastaldi and Ozturk, 2023; Goel *et al.*, 2021), consumer preferences (Gupta and Gupta, 2023; Hardman *et al.*, 2018), and technological advancements (Lal *et al.*, 2023; Siragusa *et al.*, 2022), it often bypasses the distinct challenges intrinsic to the logistics sector's shift towards electrification. Although studies like Pahwa and Jaller (2022) and Caggiani et al. (2021) highlight the operational efficiency and environmental merits of integrating EVs into last-mile delivery fleets, they rarely explore the systemic and regulatory hurdles to such integration comprehensively. Furthermore, while existing studies yield valuable insights within geographical contexts, such as European urban logistics (Caggiani et al., 2021) and consumer behaviour in Asia (Asadi *et al.*, 2022; Tarei *et al.*, 2021), they might not fully encapsulate the global intricacies of moving towards logistics electrification.

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Addressing these research gaps, our research endeavours to meticulously discern, authenticate, and prioritize impediments confronting global EV deployment for LMD.

Within the context of the current study, the research aims to address the following research questions:

* *RQ1:* *What are the specific barriers that impede the adoption of EVs in the context of LMD, as distinguished from broader EV adoption challenges within the transportation sector?*
* *RQ2: Given the current advancements and practices in LMD, how can the identified barriers to EV adoption in LMD be systematically categorized and prioritized, and which of these barriers are considered most significant by critical stakeholders involved in the sector?*
* *RQ3: Given the prioritized barriers to EV adoption in LM, what specific strategies can stakeholders develop to overcome these obstacles and promote the integration of EVs to advance sustainable freight transportation?*

This study significantly advances the discourse on EV adoption within LMD, particularly by exploring the multifaceted barriers that impede their integration into sustainable urban logistics. Contrary to the predominantly consumer-focused analyses in prior research (e.g., Asadi et al., 2022; Tarei et al., 2021), our work elucidates the logistical, infrastructural, and operational challenges that researchers seldom address comprehensively. By shedding light on the systemic and regulatory hurdles, our research contributes a granular examination of the impediments facing last-mile delivery scenarios—from the inadequacies in charging infrastructure tailored for commercial fleets to the legislative and policy constraints hindering widespread EV deployment in logistical services.

Our investigation adopts a global perspective, harnessing expert insights from various regions to transcend regional limitations and foster an understanding of the universal barriers and opportunities for EV adoption. This approach identifies and proposes actionable strategies to mitigate these barriers based on extensive consultations with stakeholders, including logistics companies, policymakers, and urban planners. This proactive stance underscores the innovative nature of our study. It enriches the ecosystem needed to support the shift towards sustainable urban freight systems—a topic less explored in the existing literature.

Ultimately, our research constructs a comprehensive framework incorporating technological, operational, socio-technical, and policy-related challenges, offering a cohesive understanding of these barriers and their implications for sustainable transport. By juxtaposing our holistic approach against the segmented analyses found in existing studies—such as the cost-based comparisons by Pahwa and Jaller (2022) and the environmental impact assessments by Siragusa et al. (2020)—our work delineates its novelty and substantial contribution to the field. It prompts further investigation and policy-making aimed at overcoming these obstacles, thereby catalysing a transition towards more sustainable urban logistics systems.

The paper is structured as follows: Section 2 offers a literature review focusing on SFT challenges. Section 3 describes the adopted research methodology. Section 4 presents the findings from the barrier analysis. Section 5 delves into an in-depth discussion of the results and culminates in the conclusions presented in Section 6.

**2. Literature Review**

*2.1 Theoretical Framework: Diffusion of Innovations (DOI)*

DOI theory provides a comprehensive framework for understanding how technologies spread across cultures (Rogers, 2003). Focusing on innovation, communication channels, time, and social systems, DOI classifies adopters from innovators to laggards, offering insights into adoption patterns and influencing factors. DOI considers complex organizational, regulatory, and economic dynamics critical to logistics (Jahanmir and Cavadas, 2018). Adopting EVs in LMD requires systemic changes, including infrastructure development and shifts in operations (Wolff and Madlener, 2019). DOI integration of societal, communicative, and temporal dimensions provides a comprehensive perspective essential for addressing the complexities of technology adoption in fields such as sustainable transport.

Studies demonstrate DOI’s relevance in sustainable technology adoption. Peters and Dütschke (2014) explored EV adoption in Denmark, highlighting the role of relative advantage and observability. Zhu *et al.* (2006) examined digital transformation technologies, emphasizing compatibility as a key driver. These examples highlight DOI’s importance in reviewing the complex barriers to technology adoption, making it a robust theoretical foundation for studying EV adoption in LMD. DOI enables researchers to assess critical factors such as EVs’ relative advantage, compatibility with logistics systems, integration complexity, trialability, and observability, all crucial for addressing challenges in EV adoption for LMD.

*2.2 Sustainable Freight Transportation (FT) and Technological Advancements*

Freight transportation (FT) is integral to the operability of supply chains (SCs), ensuring efficient movement of goods through diverse modes such as trains and trucks (Bektaş, 2017). Strategic management of FT improves efficiency, addressing critical factors like transit time, costs, pollution, and societal risks (SteadieSeifi *et al.,* 2014). As SCs globalize, the need for varied FT modes grows, especially with low-cost production locales (Centobelli *et al.,* 2021). Recognizing FT’s environmental impact, global efforts, including the EU’s goal to cut CO2 emissions by 2050, emphasize sustainability (Bask and Rajahonka, 2017).

Integrating environmental stewardship is essential given FT’s significant carbon footprint (Carter *et al.,* 2019). Diversifying transportation modes and adopting low-emission technologies offer paths to sustainability (Bask and Rajahonka, 2017). The rise of road-centric FT amplifies environmental challenges, highlighting the need for a Triple Bottom Line (TBL) approach (Centobelli *et al.*, 2021). Multi-Modal Freight Transportation (MMFT) combines multiple transport modes for efficiency and environmental benefits (Fulzele *et al*., 2019). The e-commerce boom and the advent of Industry 4.0 have increased the demand for innovative technological integration in freight logistics (Zhang *et al*., 2018; Schücking *et al*., 2017).

*2.4 The Dynamics of Last-Mile Delivery (LMD)*

Growing concerns over transportation-related emissions have amplified global efforts to promote electric vehicles (EVs) as crucial solutions to reducing air pollution and greenhouse gas (GHG) emissions (Lebrouhi *et al*., 2021). EVs encompass a range of technologies, from Battery Electric Vehicles (BEVs) to Extended-Range Electric Vehicles (ER-EVs), each with unique operational advantages. The global EV market, valued at $280 billion in July 2022, is projected to reach $1 trillion by 2026, driven by North America, Europe, and China (Dillan, 2022). Notably, electric light commercial vehicles (LCVs) surpassed passenger EVs in market share for the first time in 2022 (International Energy Agency, 2023).

BEVs, which held 98% of the electric LCV market in 2022, offer significant economic benefits in commercial settings (International Energy Agency, 2023). While electrifying medium- and heavy-duty vehicles is progressing more slowly, it remains essential to achieve carbon neutrality due to their substantial carbon footprint. Governments are enacting regulations to accelerate EV adoption (Lebrouhi *et al*., 2021).

With e-commerce giants offering innovative delivery paradigms, LMD has been identified to shoulder 32% of e-commerce’s carbon footprint (Patella *et al.*, 2020). In LMD, EVs have reduced environmental impacts, cutting CO2 emissions by 93-98% in cities like Paris and London (Juan *et al*., 2016; Giordano *et al*., 2018). However, challenges remain, including scaling EV deployment and addressing logistical barriers to widespread adoption (Patyal *et al*., 2021).

*2.6 Barriers to EV Utilization in LMD*

Despite significant EV sales growth in select countries across North America, Europe, and Asia, global adoption remains limited due to various challenges (Patyal et al., 2021). EVs disrupt established transportation paradigms, complicating market integration. Challenges include the need for battery advancements, competition from emerging technologies, and improvements in traditional vehicles (Anosike *et al*., 2023; Berkeley *et al.,* 2017).

Charging infrastructure is a significant barrier. Over half of prospective buyers express concerns about inadequate infrastructure, battery range, and vehicle charging solutions, divided into depot-based and public options (Schücking *et al*., 2017; “Electric vehicle charging stations in Europe | McKinsey”, n.d.). By 2022, public charging facilities totalled 2.7 million globally, with European projections ranging from 1.3 to 2.9 million by 2030 (International Energy Agency, 2023).

Battery constraints hinder adoption, including limited range, high costs, and safety concerns (Lebrouhi *et al.*, 2021). While battery-exchange systems address range anxiety, they introduce new issues like compatibility and infrastructure demands (Anosike *et al*., 2023). Moreover, relying solely on fuel savings is problematic due to the logistical challenges of battery management and high-mileage vehicles (Kuppusamy *et al*., 2017). Additionally, power supply demands and consumer misconceptions about EVs further deter adoption, highlighting the need for accurate information dissemination (Kannan and Hirschberg, 2016; Barisa *et al*., 2016).

**3. Research Methodology**

This study employed a structured literature search strategy meticulously tailored to construct a literature database to identify the barriers to EV adoption in LMD. While not constituting a full systematic literature review (SLR), this approach was grounded in established protocols to ensure rigour and relevance (Snyder, 2019). We designed and implemented a series of steps following an adopted literature search protocol specifically tailored to align with the objectives of this research. The process commenced with a preliminary search to define the search terms and refine the literature selection criteria, employing a multi-step methodology to aggregate, evaluate, and synthesize the relevant academic literature (Tranfield *et al*., 2003). This search strategy gathered a broad spectrum of studies and enabled a thematic analysis that directly shaped the selection of barriers for survey analysis. By systematically aligning identified barriers with the study’s aims, the structured literature search ensured that the identified barriers were both pertinent and supported by the latest academic insights, as corroborated by Tranfield *et al*. (2009).

Our research team conducted a rigorous and structured literature search process, focusing on an articulated research question that guided each phase of our analysis. This foundational question was developed to precisely identify the unique barriers impeding the adoption of EVs within LMD contexts, distinct from broader transportation challenges. This approach, underscored by Counsell (1997), ensured a methodical data collection and analysis. The primary research question for this structured literature search was: “*What are the specific barriers that uniquely impede the adoption of EVs in the context of LMD, as distinguished from broader EV adoption challenges within the transportation sector?*”.

Initially, the team conducted a pilot search to map the current landscape of the field and refine the literature selection criteria (Denyer and Tranfield, 2009). This preliminary phase was critical for identifying relevant keywords and establishing inclusion and exclusion criteria. Subsequently, the researchers conducted a more focused search using these identified keywords across selected electronic databases to gather pertinent sources. This study utilized Elsevier’s Scopus database and the ISI Web of Science (WoS) – Core Collection database from Thomson Reuters. Scopus was specifically chosen due to its comprehensive coverage as the largest abstract and citation database of peer-reviewed literature (Palmaccio *et al.*, 2021), while the WoS was selected for its renowned capability to provide extensive and reliable citation data for scholarly publications (Talwar *et al.*, 2021).

Rowley and Slack (2004) underscore the importance of using specific search strings to enhance the effectiveness of article retrieval. The team confined the search scope to titles, abstracts, and keywords within the Scopus and Web of Science (WoS) databases. Our systematic literature review strategy incorporated a comprehensive set of terms including “Electric Vehicles,” “Electric freight,” “Electric cargo,” “Barriers,” “Obstacles,” “Impediments,” “Adoption,” “Sustainable Freight Transport,” “Green Transport,” “Green Vehicles,” “Battery Technology,” “Urban Logistics,” “City logistics,” “E-commerce,” “Last-mile,” “Renewable energy,” “Sustainable mobility,” “Sustainable supply chain,” “Barriers to EV adoption,” and “Consumer Attitudes towards EVs.” Boolean operators—precisely “AND”, “OR,” and “NOT”—were strategically applied to refine the search outcomes, aiming to enhance both precision and relevance. Key article details were meticulously recorded and organized within a Microsoft Excel database.

The initial screening process involved the assessment of titles, abstracts, and keywords to ensure their pertinence to barriers associated with EVs in last-mile logistics. Only literature that directly addressed the adoption of EVs and the associated barriers within the transportation sector was selected. The final selection of articles was subject to a thorough full-text review conducted by multiple researchers. This stage included cross-referencing and additional searches on Google Scholar, which is recognized for its ability to uncover non-indexed works, thereby expanding the scope of the literature search (Lyu *et al.*, 2022). The team enriched the inclusion phase with further publications identified through cross-referencing and sourced additional peer-reviewed articles from Google Scholar.

Following the structured literature search, we implemented a thematic analysis to identify and categorize the barriers to electric vehicle adoption in Last-Mile Deliveries (LMD). This essential phase enabled us to systematically organize the varied barriers into coherent themes, revealing prevalent patterns and shared challenges. Using NVivo 12, the analysis was conducted through independent coding and subsequent consensus to finalize the themes, utilizing an inductive approach. This approach ensured that the themes identified were directly informed by the existing literature, enhancing the relevance and accuracy of our findings (Banijamali *et al*., 2020).

Each theme was rigorously defined and substantiated by a synthesis of the literature. This structured thematic approach underscored the predominant barriers and systematically addressed the complex interactions and dependencies among them. The resulting coding framework incorporated categories for barriers, theoretical frameworks, data collection and analysis methodologies, types of articles, industrial contexts, geographical distribution, and potential avenues for future research. These themes were critically discussed in the results section, linking to the literature to highlight how our findings align with or diverge from existing research.

The research team further examined the identified themes through a structured questionnaire to validate the findings. This questionnaire was developed with industry experts and academic authorities to ensure its comprehensiveness and validity. Before its widespread implementation, the questionnaire was subjected to beta testing to enhance its clarity and ensure the consistency of responses.

Table 1 provides a comprehensive overview of the primary barriers to EV adoption in LMDs as identified through the literature, organised by theme.

Table 1. Summary of barriers to EV adoption in LMD

|  |  |  |  |
| --- | --- | --- | --- |
| **Code**  | **Barriers**  | **Explanation of Barriers**  | **Sources**  |
| B1  | Insufficient charging infrastructure  | Insufficient charging infrastructure, such as a lack of charging stations, can result in an inflexible and inconvenient energy supply, making EV operations less appealing.  | (Aungkulanon *et al.*, 2023; Berkeley *et al.*, 2017; Biresselioglu *et al.*, 2018; Kuppusamy *et al.*, 2017; Noel *et al.*, 2020; Patyal *et al.*, 2021; Tarei *et al.*, 2021). |
| B2  | Deficiency of depot-based fast charging  | A depot-based charging station requires installation in central locations, such as a depot or parking lot, where EVs can be charged while not in use, typically utilized in fleet operations.  | (D’Adamo, Gastaldi, Piccioni, *et al.*, 2023; Patyal *et al.*, 2021). |
| B3  | Insufficient Electricity Provision  | Increased electric mobility leads to a surge in electricity demand, which can be challenging for countries that intend to phase out nuclear energy and shift towards renewable energy sources. Renewable energy sources alone may not satisfy the growing need for electricity, and those peak loading periods are unlikely to provide access to affordable electricity.  | (Biresselioglu *et al.*, 2018).  |
| B4  | Increased investment for Power Grid upgrade  | The current power network system may not be adequate to charge a commercial fleet; hence, upgrading the grid demands investment.  | (Anosike *et al.*, 2023; Morganti and Browne, 2018; Schücking *et al.*, 2017). |
| B5  | Extended charging duration  | Charging EVs in stations takes a long time, making EV adoption difficult.  | (Anosike *et al.*, 2023; Biresselioglu *et al.*, 2018; Pelletier *et al.*, 2018).  |
| B6  | Limited range availability  | EVs have a lower driving range than ICEVs due to technical and financial limitations in energy storage.  | (Anosike *et al.*, 2023; Biresselioglu *et al.*, 2018; Christensen *et al.*, 2017; Noel *et al.*, 2020; Wikström *et al.*, 2015). |
| B7  | Range Uncertainty  | Drivers feel that their vehicle could run out of battery charge before reaching their destination and that there is a possibility of not finding a charging station for recharging.  | (Anosike *et al.*, 2023; Berkeley *et al.*, 2017; Christensen *et al.*, 2017; Tarei *et al.*, 2021).  |
| B8  | Limited Loading Capacity  | The weight and size of EVs pose a further issue, reducing payload capacity compared to traditional vehicles. The additional weight of the battery contributes to a reduction in the automobile's freight capacity. | (Anosike *et al.*, 2023; Christensen *et al.*, 2017; Morganti and Browne, 2018, 2018).  |
| B9  | Limited Raw Material Availability  | The increasing demand for EVs requires considerable raw materials, some rare metals with an irregular supply.  | (Biresselioglu *et al.*, 2018)  |
| B10  | Battery costs  | Although EVs can reduce fuel, their economic viability may be lower due to high battery prices.  | (Biresselioglu *et al.*, 2018; Lal *et al.*, 2023).  |
| B11  | Battery lifespan  | The high utilization of batteries in LMD makes buyers think their useful life is short. | (Gao *et al.*, 2019; Pelletier *et al.*, 2018; Schücking *et al.*, 2017).  |
| B12  | Inadequate infrastructure for battery swapping  | The insufficient availability of battery swapping stations limits the practicality of battery switching to reduce EV range anxiety and increase the driving range.  | (Anosike *et al.*, 2023; Keskin and Çatay, 2016; Kuppusamy *et al.*, 2017).  |
| B13  | Inventory cost for battery swapping  | Holding a sufficient inventory of fully charged batteries for swapping results in additional expenses, increasing the overall costs of EV operations.  | (Anosike *et al.*, 2023; Kuppusamy *et al.*, 2017).  |
| B14  | The high initial upfront price  | Due to limited production, the high purchase cost of EVs can be a significant barrier to fleet operations' adoption.  | (Biresselioglu *et al.*, 2018; D’Adamo, Gastaldi and Ozturk, 2023; D’Adamo, Gastaldi, Piccioni, *et al.*, 2023; Knupfer *et al.*, 2016; Patyal *et al.*, 2021; Siragusa *et al.*, 2022).  |
| B15  | Maintenance cost  | The maintenance expenses of EVs are significantly lower than those of conventional vehicles since they have fewer moving components. However, in the case of a failure, repair costs might become prohibitive, and the availability of infrastructure for regular upkeep, service, and fixing is questionable.  | (Berkeley *et al.*, 2017; Goel *et al.*, 2021) .  |
| B16  | Total Cost of Ownership  | TCO includes upfront costs, maintenance, electricity and other costs. Despite long-term savings, perceived high TCO often deter potential buyers, reducing the transition to sustainable transportation.  | (Anosike *et al.*, 2023; Asadi *et al.*, 2022; Caggiani *et al.*, 2021; Selter *et al.*, 2024; Tarei *et al.*, 2021).  |
| B17  | Socio-technical barriers  | For EVs to be successfully adopted, acceptance by consumers is essential. Socio-technical constraints, customer worries and perceptions, operational difficulties related to a lack of faith in the technology, and insufficient training hinder EV adoption. | (Anosike *et al.*, 2023; Berkeley *et al.*, 2017; Noel *et al.*, 2020; Wikström *et al.*, 2015). |
| B18  | Lack of trust in environmental benefits  | Most prospective EV buyers are misinformed and unaware of their sustainable effects. EVs are perceived to increase CO2 emissions due to increased power demands, battery disposal issues, and uncertainty about environmental benefits. | (Asadi *et al.*, 2022; Barisa *et al.*, 2016; Biresselioglu *et al.*, 2018; Gupta and Gupta, 2023). |
| B19  | Uncertainty Over Resale Value  | The uncertainty and lack of clear information regarding the potential future resale value of EVs pose a concern for potential buyers, as it may impact their ability to recover a significant portion of their initial investment upon selling the vehicles.  | ( Gupta and Gupta, 2023)  |
| B20  | Limited variety of models  | A shortage of diversity of vehicles makes it difficult to improve market acceptability since there are not enough models to satisfy all of the different customer segments' demands and expectations.  | (Barisa *et al.*, 2016; Biresselioglu *et al.*, 2018).  |
| B21  | Policy and Regulatory obstacles  | The existing legal and regulatory framework in specific regions or countries presents challenges or barriers, including laws, regulations, or policies that inadvertently or intentionally impede the adoption, use, or development of EVs.  | (Bruzzone *et al.*, 2021; Goel *et al.*, 2021; Morganti and Browne, 2018).  |

As shown in Fig. 1, the research methodology follows a tripartite structure. An extensive literature review initially yielded 21 potential barriers (Table 1). The subsequent phase involved empirical inquiry through a quantitative survey, collating insights from 157 industry professionals. *Appendix I* presents the detailed survey instrument. This data underwent an Exploratory Factor Analysis (EFA) for barrier categorization and validation. The culminating stage adopted the AHP for a hierarchical barrier ranking, emphasizing their contextual relevance in EV uptake.

*---------------------------------------------- Insert Fig. 1 -------------------------------------------------*

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 Fig 1. Implementation Process of the Research Methodology

We strategically chose the application of EFA to discern and validate the underlying dimensions among a broad array of identified barriers. This study reinforces the utility of EFA by its capacity to uncover latent structures without presupposing a specific model. This approach is crucial for empirical rigour and the integrity of our barrier categorization. This methodological choice reflects the recommendations of (Osborne, 2014), who advocate for EFA’s use in exploratory studies to identify factor structures among variables. On the other hand, we chose the Analytical Hierarchy Process (AHP) in this study to align with our research objectives and ensure a robust analytical framework. The well-documented efficacy of the AHP in structuring complex decision-making scenarios and its proficiency in facilitating the prioritization of factors through pairwise comparisons guided our decision to utilize AHP over the Analytic Network Process (ANP). This characteristic of AHP was particularly beneficial for systematically categorising and ranking the diverse barriers to EV adoption in LMD.

Collectively, the integration of EFA and AHP in our research methodology is not only methodologically sound but also supported by a substantial body of literature that attests to their robustness and appropriateness for the aims of our study (Dwivedi *et al.*, 2022; Singh *et al.*, 2023).

*3.1 Data collection and analysis*

An appended survey questionnaire in Qualtrics harvested these up-to-date expert perspectives, subsequently facilitating barrier validation and categorization via EFA. Researchers gathered data within the defined period of the research's time horizon. The AHP then ranked these barriers, drawing upon expert panel feedback.

The study disseminated the survey through email and LinkedIn, the latter capitalizing on a diverse network of scholars and practitioners. This approach conforms to the suggested 5:1 ratio of respondents to variables for EFA, as outlined by Reio and Shuck (2015), to secure a minimum of 105 survey participants. Post-collection data underwent stringent cleaning, coding, and validation in SPSS (Version 28). Demographic analyses and EFA proceeded using SPSS to structure the barriers into coherent clusters. The utilization of the AHP facilitated the structured ranking of the identified barriers.

**4. Analysis and Results**

*4.1 Data Cleansing and Coding*

The team applied meticulous data cleansing and coding procedures to ensure the integrity of the data analysis. Initially, a total of 201 responses were collected. After conducting a detailed review for completeness and consistency, the researchers excluded 37 responses due to incomplete data and omitted an additional seven due to uniform responses across the 21 barriers evaluated. Consequently, 157 responses were deemed suitable for further analysis. This final sample size not only meets but exceeds the projected requirement of 105 participants, as outlined in Section 3.1, providing a robust basis for statistical reliability and the EFA (Maskey *et al.*, 2018). For clarity and reference, we categorized demographic data as 'DMa' and tagged details concerning barriers as 'Ba', with specifics provided in Table 2 and Table 3, respectively.

*4.2 Demographic Analysis*

Table 2 details these demographics, providing a breakdown of the participant distribution across these categories, ensuring a diverse and representative sample that supports the validity of the study’s conclusions.

 Table 2. Demographic Analysis of Survey Data

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables**  | **Received Responses**  | **Frequency** | **Per cent** |
| DM1: Position  | Manager/Supervisor  | 95.00 | 60.51 |
|  | Executive  | 28.00 | 17.83 |
|  | Other  | 27.00 | 17.20 |
|  | Engineer  | 7.00 | 4.46 |
|  | Total | 157 | 100.00 |
| DM2: Experience  | More than five years  | 87.00 | 55.41 |
|  | Between 3 and 5 years  | 38.00 | 24.20 |
|  | Less than three years  | 32.00 | 20.38 |
|  | Total | 157 | 100.00 |
| DM3: Industry  | Logistics, Courier, and Postal Services  | 61.00 | 38.85 |
|  | Retail and E-commerce  | 56.00 | 35.67 |
|  | Other  | 35.00 | 22.29 |
|  | Food Delivery and Catering Services  | 5.00 | 3.18 |
|  | Total | 157 | 100.00 |
| DM4: Organization Size  | Large (250 employees or above)  | 106.00 | 67.52 |
|  | Medium (50-249 employees)  | 27.00 | 17.20 |
|  | Small (1-49 employees)  | 24.00 | 15.29 |
|  | Total | 157 | 100.00 |
| DM5: Region  | Europe  | 53.00 | 33.76 |
|  | Asia Pacific  | 27.00 | 17.20 |
|  | Multiple regions  | 22.00 | 14.01 |
|  | North America  | 17.00 | 10.83 |
|  | Africa  | 14.00 | 8.92 |
|  | South America  | 12.00 | 7.64 |
|  | Middle East  | 11.00 | 7.01 |
|  | Other  | 1.00 | 0.64 |
|  | Total | 157 | 100.00 |

*4.3 Assessment of Reliability and Validity*

Ensuring the reliability and validity of the survey instrument is fundamental for maintaining the integrity and consistency of the data collected, which underpins the credibility of the analysis (Hair, 2010). To this end, the research team captured responses through a secure survey platform and preserved them on a password-protected drive. The data, designated by variable codes B1 through B21, underwent a rigorous reliability assessment employing Cronbach's Alpha. The computed Alpha value of 0.853 significantly surpassed the accepted benchmark of 0.7, underscoring the reliability of the survey data (Taber, 2018). We systematically present these statistical details in Table 3.

Given the cross-sectional nature of our study, where participants provided their responses only once, the survey’s reliability relied solely on internal consistency, as temporal stability measures were not applicable.

 Table 3. Reliability Test Outcome of Survey Data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **EV Adoption Barriers in LMD Operations**  | **Cronbach’s Alpha****if Item Deleted** | Mean | SD |
| B1 | Insufficient Charging Infrastructure  | 0.848 | 3.94 | 1.12 |
| B2 | Deficiency of depot-based fast charging  | 0.851 | 3.89 | 1.01 |
| B3 | Insufficient Electricity Provision  | 0.847 | 3.59 | 1.20 |
| B4 | Increased investment for Power Grid upgrade  | 0.849 | 3.74 | 1.10 |
| B5 | Longer charging duration  | 0.846 | 3.68 | 1.06 |
| B6 | Limited Range Availability  | 0.854 | 3.68 | 1.17 |
| B7 | Range Uncertainty  | 0.847 | 3.52 | 1.07 |
| B8 | Limited loading capacity  | 0.849 | 3.43 | 1.19 |
| B9 | Limited raw material availability  | 0.844 | 3.39 | 1.24 |
| B10 | Battery costs  | 0.848 | 3.55 | 1.08 |
| B11 | Battery lifespan  | 0.844 | 3.56 | 1.14 |
| B12 | Inadequate infrastructure for battery swapping  | 0.845 | 3.39 | 1.17 |
| B13 | Inventory cost for battery swapping  | 0.842 | 3.16 | 1.11 |
| B14 | High initial purchase cost  | 0.849 | 3.80 | 1.11 |
| B15 | Maintenance cost  | 0.842 | 3.30 | 1.24 |
| B16 | Total Cost of Ownership  | 0.842 | 3.70 | 1.11 |
| B17 | Socio-technical barriers  | 0.850 | 3.01 | 1.09 |
| B18 | Lack of trust in environmental benefits  | 0.850 | 2.90 | 1.12 |
| B19 | Uncertainty Over Resale Value  | 0.842 | 3.17 | 1.20 |
| B20 | Limited variety of models  | 0.852 | 2.98 | 1.12 |
| B21 | Policy and Regulatory obstacles  | 0.846 | 3.32 | 1.23 |

A specialized panel comprising eight experts from both academic and industrial sectors conducted a pilot test to confirm face validity. The feedback led to minor revisions, overall affirming the survey's appropriateness. The research team assessed divergent validity by applying the Pearson Correlation Coefficient to the rated barriers, see Table 4. Observed variables exhibited weak to moderate correlations, all falling beneath an absolute value of 0.6, suggesting distinct criteria for measuring each barrier (Akoglu, 2018). Additionally, Table 3 showcases the results of the descriptive analysis, where mean values exceeded the threshold of 2.5, underlining the significance of the barriers and thereby justifying their inclusion in the EFA (Taber, 2018).

Table 4. Correlation Matrix of the barriers to EV adoption in LMD based on Pearson Correlation coefficients.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **B1**  | **B2**  | **B3**  | **B4**  | **B5**  | **B6**  | **B7**  | **B8**  | **B9**  | **B10**  | **B11**  | **B12**  | **B13**  | **B14**  | **B15**  | **B16**  | **B17**  | **B18**  | **B19**  | **B20**  | **B21**  |
| B1  | 1 | 0.53  | 0.41  | 0.32  | 0.27  | 0.18  | 0.31  | 0.23  | 0.09  | 0.10  | 0.12  | 0.13  | 0.21  | 0.08  | 0.19  | 0.22  | 0.14  | 0.09  | 0.19  | 0.01  | 0.27  |
| B2  |  | 1  | 0.40  | 0.31  | 0.24  | 0.23  | 0.21  | 0.22  | 0.17  | 0.06  | 0.07  | 0.15  | 0.09  | -0.01  | 0.18  | 0.10  | 0.00  | 0.08  | 0.14  | -0.08  | 0.17  |
| B3  |  |  | 1  | 0.52  | 0.32  | 0.19  | 0.29  | 0.25  | 0.28  | 0.02  | 0.16  | 0.14  | 0.15  | 0.18  | 0.26  | 0.13  | 0.13  | 0.12  | 0.12  | -0.02  | 0.27  |
| B4  |  |  |  | 1  | 0.16  | 0.16  | 0.13  | 0.22  | 0.29  | 0.05  | 0.16  | 0.08  | 0.15  | 0.06  | 0.17  | 0.08  | 0.12  | 0.12  | 0.21  | 0.08  | 0.29  |
| B5  |  |  |  |  | 1  | 0.31  | 0.26  | 0.23  | 0.22  | 0.21  | 0.21  | 0.27  | 0.23  | 0.30  | 0.16  | 0.20  | 0.04  | 0.19  | 0.37  | 0.14  | 0.28  |
| B6  |  |  |  |  |  | 1 | 0.37  | 0.35  | 0.08  | -0.07  | 0.08  | 0.05  | 0.19  | 0.11  | 0.02  | 0.16  | -0.10  | 0.04  | 0.13  | 0.14  | 0.05  |
| B7  |  |  |  |  |  |  | 1 | 0.39  | 0.15  | 0.13  | 0.28  | 0.28  | 0.36  | 0.23  | 0.23  | 0.20  | 0.13  | 0.08  | 0.14  | 0.06  | 0.09  |
| B8  |  |  |  |  |  |  |  | 1 | 0.17  | -0.01  | 0.20  | 0.22  | 0.13  | 0.10  | 0.27  | 0.24  | 0.09  | 0.02  | 0.14  | 0.18  | 0.15  |
| B9  |  |  |  |  |  |  |  |  | 1 | 0.36  | 0.38  | 0.26  | 0.35  | 0.25  | 0.38  | 0.38  | 0.28  | 0.11  | 0.27  | 0.25  | 0.23  |
| B10  |  |  |  |  |  |  |  |  |  | 1 | 0.44  | 0.26  | 0.41  | 0.39  | 0.38  | 0.39  | 0.27  | 0.14  | 0.29  | 0.19  | 0.19  |
| B111  |  |  |  |  |  |  |  |  |  |  | 1 | 0.44  | 0.40  | 0.47  | 0.40  | 0.34  | 0.16  | 0.23  | 0.28  | 0.22  | 0.17  |
| B12  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.54  | 0.31  | 0.29  | 0.40  | 0.17  | 0.25  | 0.33  | 0.19  | 0.17  |
| B13  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.35  | 0.4  | 0.45  | 0.34  | 0.26  | 0.34  | 0.14  | 0.23  |
| B14  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.28  | 0.39  | 0.10  | 0.06  | 0.20  | 0.11  | 0.00  |
| B15  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.56  | 0.21  | 0.16  | 0.30  | 0.11  | 0.47  |
| B16  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.18  | 0.13  | 0.40  | 0.26  | 0.29  |
| B17  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.45  | 0.38  | 0.19  | 0.34  |
| B18  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.51  | 0.19  | 0.30  |
| B19  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.30  | 0.38  |
| B20  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 0.26  |
| B21  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |

\*Note: The study did not incorporate significance levels for 2-tailed tests because there was no requirement for this data in the assessment.

*4.4 Structural Analysis of EV Adoption Barriers*

The research team first confirmed the suitability of the dataset for Exploratory Factor Analysis (EFA) through the Kaiser-Meyer-Olkin (KMO) measure, which yielded a value of 0.781. This value significantly exceeds the recommended threshold of 0.6, affirming the adequacy of the sample size for factor analysis (Eisinga *et al.*, 2013). Concurrently, Bartlett’s Test of Sphericity indicated a significance level of 0.001, well below the acceptable cut-off of 0.05 (Shrestha, 2021), further substantiating the dataset's appropriateness for conducting EFA to explore barriers impacting the adoption of electric vehicles (EVs) in last-mile logistics.

The EFA initiated with Principal Component Analysis (PCA) of the 21 barrier variables, identifying six initial factors with eigenvalues exceeding 1 (Luthra and Mangla, 2018), collectively explaining 61.46% of the total variance. Although this is below the recommended 75% threshold for total variance explained (Yong and Pearce, 2013), it exceeds the minimum acceptable variance of 50%, as Shrestha (2021) suggested, validating the factor solution's robustness. A Varimax orthogonal rotation method—was applied to enhance interpretability, facilitating a more precise understanding and simplifying factor loadings (Osborne, 2019). During this phase, we disregarded any factor loadings below 0.40, aligning with standard practices for retaining significant loadings in EFA.

Subsequent iterations focused on refining the factor structure. Initial analyses indicated that Barrier 9 (B9) loaded significantly onto the first factor, with a disparity in cross-loading above the threshold of 0.10 (Zhang et al., 2018). This analysis also revealed inadequacies in the fifth and sixth factors, which contained fewer than the recommended three items with substantial loadings, prompting a reduction in the number of factors from six to four (Samuels, 2017).

We reanalysed the factor structure to resolve cross-loading issues and realign the factors according to their highest loadings, following guidelines by Zhang et al. (2018). This process confirmed the absence of significant cross-loading problems, and the adjusted factor solution presented a coherent and relevant categorization of the barriers. The final EFA model comprised four factors, collectively accounting for 51.28% of the variance, consistent with the guideline that common variance should exceed 50% (Williams *et al.*, 2010).

The results of this comprehensive factor analysis are summarized in Table 5. This structure was subsequently validated through consultation with industry experts, ensuring the practical relevance and applicability of the findings to last-mile EV adoption.

 Table 5. Categorization of Barriers to EV Adoption in the LMD

|  |  |  |  |
| --- | --- | --- | --- |
| Factor  | Category | Barriers to EV adoptions in LMD |  Factor Loadings |
| 1 | 2 | 3 | 4 |
| 1 | Financial and Resource Barriers (FR)  | Limited raw material availability (FR1)  | 0.55  |  |  |  |
| Battery costs (FR2)  | 0.71  |  |  |  |
| Battery lifespan (FR3)  | 0.70  |  |  |  |
| Infrastructure for battery swapping (FR4)  | 0.56  |  |  |  |
| Inventory cost for battery swapping (FR5)  | 0.64  |  |  |  |
| High initial purchase cost (FR6)  | 0.69  |  |  |  |
| Maintenance cost (FR7)  | 0.63  |  |  |  |
| Total Cost of Ownership (FR8)  | 0.66 |  |  |  |
| 2 | Energy and Charging Infrastructure Barriers (EI) | Insufficient Charging Infrastructure (EI1)  |  | 0.67  |  |  |
| Deficiency of depot-based fast charging (EI2)  |  | 0.70  |  |  |
| Insufficient Electricity Provision (EI3)  |  | 0.75  |  |  |
| Investment for Power Grid upgrade (EI4)  |  | 0.68  |  |  |
| 3 | Policy, Perception, and Market Barriers (PPM)  | Socio-technical barriers (PPM1) |  |  | 0.66  |  |
| Lack of trust for environmental benefits (PPM2)  |  |  | 0.76  |  |
| Uncertainty Over Resale Value (PPM3)  |  |  | 0.70  |  |
| Limited variety of models (PPM4)  |  |  | 0.50  |  |
| Policy and Regulatory Obstacles (PPM5)  |  |  | 0.58  |  |
| 4 | Operational and Technical Barriers (OT)  | Longer charging duration (OT1)  |  |  |  | 0.47  |
| Limited Range Availability (OT2)  |  |  |  | 0.79  |
| Range Uncertainty (OT3)  |  |  |  | 0.62  |
| Limited loading capacity (OT4)  |  |  |  | 0.61  |
| Eigenvalues  | 5.493  | 2.280  | 1.679  | 1.318  |
| Total Variance explained (%)  | 26.16  | 37.02  | 45.01  | 51.29  |

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations.

*4.5 Hierarchical Prioritization of EV Adoption Barriers for LMD using AHP*

*4.5.1 Formulation of Research Objective*

AHP begins with defining the research objective, which is crucial for guiding the analysis (Saaty, 2008). In this study, AHP evaluated and prioritised the barriers to adopting EVs in LMD. Unlike other methodologies that require large samples, AHP focuses on the depth and quality of expert insights (Luthra *et al.*, 2017). Accordingly, this study engaged a panel of five experts with extensive experience in supply chain management and LMD operations across different geographical contexts:

* A Senior Director from EMEA with 34 years of experience,
* An Assistant General Manager from the United States with 27 years of experience,
* A Strategic Programs Director from the Netherlands with 30 years of experience,
* A Supply Chain Consultant from the United Kingdom with 31 years of experience,
* A Director of Logistics from Brazil and Europe with 25 years of experience.

We selected these experts based on their diverse professional backgrounds and their comprehensive understanding of the challenges associated with EV adoption in logistics.

*4.5.2 AHP Application and Results*

The experts performed pairwise comparisons of the barriers identified from the EFA using Saaty's nine-point scale, which assesses the relative importance of factors against each other (Saaty, 2008). The results of this hierarchical analysis, depicted in Figure 2, highlight the relative importance of each barrier and provide a clear visual representation of how these barriers interrelate and impact the adoption of EVs in the context of LMD.



Fig 2. EV adoption barriers to decision hierarchy

*4.5.3 Calculation of Relative Weights and Evaluating Consistency Ratio*

We aggregated the pairwise comparison data collected from experts to determine the relative priority weights of various barriers to the adoption of EVs in LMD. The aggregation method chosen was the median, favoured over the mean due to its more excellent resistance to outliers, enhancing the statistical robustness of the results. The results are presented in Table 6.

Table 6. Pairwise comparison matrix of four main barriers and their relative weights

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Major Barrier Dimensions**  | **FR** | **EI** | **PPM** | **OT** | **Relative Weight** | **Rank** |
| Financial and Resource Barriers (FR)  | 1 | 0.33 | 5 | 2 | 0.2924 | 2nd |
| Energy and Infrastructure Barriers (EI)  | 3 | 1 | 4 | 1 | 0.3866 | 1st |
| Public Policy, Perception and Market Barriers (PPM)  | 0.20 | 0.25 | 1 | 0.25 | 0.0674 | 4th |
| Operational and Technical Barriers (OT)  | 0.50 | 1 | 4 | 1 | 0.2536 | 3rd |
| C.I.= 0.1130; CR= 0.1256 |

To ensure the reliability of the rankings derived from AHP, we calculated the consistency ratio (CR) for each pairwise comparison matrix. Maintaining a CR (≤ 0.2) is essential as it indicates a reasonable level of consistency in the judgments made by the experts (Pauer *et al.*, 2016). This meticulous approach to verifying consistency solidified the reliability of the findings. Table 7 elaborates on the specific obstacles under each dimension, providing a hierarchical breakdown based on their relative weights and global ranks:

Table 7. Ranking of EMV implementation barriers in LMD

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Dimension of Barriers**  | **Relative Weights**  | **Barriers**  | **Relative Weights**  | **Relative Rank**  | **Global Weights**  | **Global Rank**  |
| Financial and Resource Barriers (FR)  | 0.2924  | FR1 - Limited raw material availability  | 0.0766 | 6th | 0.0224 | 14th |
| FR2 - Battery costs  | 0.1337 | 4th | 0.0391 | 12th |
| FR3 - Battery lifespan  | 0.0780 | 5th | 0.0228 | 13th |
| FR4 - Inadequate infrastructure for battery swapping  | 0.0451 | 7th | 0.0132 | 18th |
| FR5 - Inventory cost for battery swapping  | 0.0430 | 8th | 0.0126 | 19th |
| FR6 - High initial purchase cost  | 0.1922 | 3rd | 0.0562 | 9th |
| FR7 - Maintenance cost  | 0.2092 | 2nd | 0.0612 | 8th |
| FR8 - Total Cost of Ownership  | 0.2222 | 1st | 0.0650 | 5th |
| Energy and Infrastructure Barriers (EI)  | 0.3866  | EI1 - Insufficient Charging Infrastructure  | 0.1267 | 4th | 0.0490 | 10th |
| EI2 - Deficiency of depot-based fast charging  | 0.4271 | 1st | 0.1651 | 1st |
| EI3 - Insufficient Electricity Provision  | 0.2326 | 2nd | 0.0899 | 2nd |
| EI4 - Increased investment for Power Grid upgrade  | 0.2135 | 3rd | 0.0826 | 3rd |
| Public Policy, Perception and Market Barriers (PPM)  | 0.0674  | PPM1 - Socio-technical barriers  | 0.2425 | 2nd | 0.0163 | 16th |
| PPM2 - Lack of trust for environmental benefits  | 0.1011 | 5th | 0.0068 | 21st |
| PPM3 - Uncertainty Over Resale Value  | 0.2084 | 3rd | 0.0140 | 17th |
| PPM4 - Limited variety of models  | 0.1442 | 4th | 0.0097 | 20th |
| PPM5 - Policy and Regulatory obstacles  | 0.3039 | 1st | 0.0205 | 15th |
| Operational and Technical Barriers (OT)  | 0.2536  | OT1 - Longer charging duration  | 0.2417 | 2nd | 0.0613 | 6th |
| OT2 - Limited Range Availability  | 0.3250 | 1st | 0.0824 | 4th |
| OT3 - Range Uncertainty  | 0.2417 | 3rd | 0.0613 | 7th |
| OT4 - Limited loading capacity  | 0.1917 | 4th | 0.0486 | 11th |

**5. Discussion**

This research systematically evaluates barriers to EV adoption in Last-Mile Delivery (LMD), leveraging a comprehensive literature review and insights from 157 industry experts to validate 21 identified obstacles empirically. Through EFA and expert feedback, these barriers were categorised into four critical dimensions—EI, FR, OT, and PPM. Finally, AHP was used to prioritise the barriers, ranked by their impact on adoption rates. This structured prioritisation clarifies the distinct challenges impeding EV integration into LMD and guides strategic resource allocation and policy development to enhance the sustainability of freight transport.

This study incorporates a Diffusion of Innovations (DOI) framework to analyse how relative advantage, compatibility, complexity, trialability, and observability impact EV adoption rates in Last-Mile Delivery (LMD). Each barrier identified correlates with specific DOI aspects, profoundly influencing the diffusion process in this sector. Integrating the theoretical framework into our analysis helps develop DOI-aligned interventions significantly enhancing EV integration into logistics systems. This approach boosts the effectiveness of adoption strategies and roots these efforts in a solid theoretical base, ensuring a holistic and sustainable transition to electric last-mile deliveries by comprehensively addressing technological, economic, operational, and policy challenges.

*5.1 Dimension 1: Energy and Infrastructure Barriers (EI)*

Our investigation reveals that energy and infrastructure (EI) barriers constitute the most formidable obstacles to the adoption of EVs in LMD. According to DOI, the compatibility and complexity of new technologies with existing systems are crucial for their adoption. Challenges such as inadequate charging infrastructure and the lack of energy provision influence these DOI elements by presenting systemic incompatibilities that hinder the seamless integration of EVs into existing logistics networks. These barriers, which include inadequate charging facilities and insufficient energy provision, pose systemic incompatibilities that disrupt the integration of EVs into existing logistics frameworks. This challenge is emphasised by Aungkulanon *et al*. (2023) and Tarei *et al*. (2021), who highlight the essential alignment of new infrastructural developments with existing transportation systems to facilitate EV adoption. Hardman *et al*. (2018) further stress the necessity of robust charging solutions, underscoring our call for strategic infrastructure enhancements to advance sustainable transport within the logistics sector.

In our study, the most pivotal barrier identified is the ‘Deficiency of depot-based fast charging (EI2),’ which is essential due to the dependency of logistics operations on effective depot-based charging strategies (Morganti and Browne, 2018). This challenge is exacerbated by the need for meticulous scheduling to manage continuous charging demands efficiently, mainly when off-peak charging is not feasible (Pelletier *et al*., 2018; Anosike *et al*., 2023). Furthermore, ‘Insufficient Electricity Provision (EI3)’ emerges as a significant constraint, as the growing adoption of EVs increases the load on power grids, necessitating an urgent expansion of energy production from renewable sources to support these demands (“*Electric vehicle charging stations in Europe | McKinsey*”). These barriers underscore the technological and infrastructural challenges faced and highlight critical compatibility issues within the Diffusion of Innovations (DOI) framework, impacting the rate of EV integration into existing systems.

In our analysis, two additional critical barriers emerge within the Energy and Infrastructure (EI) dimension. Firstly, ‘Increased investment for Power Grid upgrade (EI4)’ highlights the insufficiency of current power grids to support the needs of an entire EV fleet, demanding significant upgrades to prevent overloads and power outages (Anosike *et al*., 2023). This necessity underscores the need for infrastructural evolution to accommodate new technologies, reflecting the complexities of adoption within the Diffusion of Innovations (DOI) framework. Secondly, ‘Insufficient Charging Infrastructure (EI1)’ illustrates the reluctance of both public and private sectors to invest in adequate charging stations, exacerbated by the slow adoption rates and limited number of EVs on the roads (Aungkulanon *et al.*, 2023). This barrier complicates EVs’ trialability and impedes their broader acceptance and integration into existing systems.

The paucity of charging stations in urban areas poses a formidable barrier to the adoption of electric vehicles (EVs) in last-mile deliveries, significantly hampering operational efficiency (“*World energy transitions outlook 2022*”). This observation aligns with our findings and is further supported by Mersky *et al.* (2016) and Lebeau *et al.* (2016), who highlight the consumer demand for accessible charging options and the critical need for expansive infrastructure. While Noel *et al*. (2020) confirm ongoing infrastructural challenges, Giordano *et al*. (2018) suggest that swift infrastructural advancements could ameliorate these obstacles, offering a hopeful outlook for future integration efforts.

*5.2 Dimension 2: Financial and Resource Barriers (FR)*

The Financial and Resource (FR) barriers ranked as the second most influential, underscore the economic challenges in adopting electric vehicles (EVs) in Last-Mile Delivery (LMD). This prioritisation points to the need to understand better the economic incentives that can accelerate adoption, such as subsidies, tax incentives, and cost-sharing models. These barriers align with the Diffusion of Innovations (DOI) theory, particularly the constructs of ‘relative advantage’ and ‘economic compatibility’. High ownership costs impact perceived economic benefits and trialability, as noted by Tarei et al. (2021) and further elaborated by D’Adamo, Gastaldi, Piccioni, *et al*. (2023) and D’Adamo, Gastaldi, and Ozturk (2023). Addressing these challenges necessitates financial incentives, reduced ownership costs, and showcased long-term economic benefits to enhance EV adoption. By lowering these costs and demonstrating the long-term economic benefits, stakeholders can improve the relative advantage of EVs, thereby increasing their attractiveness and potential trialability among prospective users. Policymakers and stakeholders are pivotal in mitigating these economic barriers to facilitate broader EV integration.

In our analysis, the economic challenges of adopting electric vehicles (EVs) in Last-Mile Deliveries, such as high initial costs and maintenance expenses, emerge as significant barriers compared to Internal Combustion Engine Vehicles (ICEVs). These factors, emphasised by Siragusa *et al.* (2022), critically influence adoption decisions by affecting the perceived benefits, a core component of the Diffusion of Innovations (DOI) theory. Moreover, the need for substantial infrastructure investment and the risks linked to uncertain residual values, highlighted by Lal *et al.* (2023), necessitate strategic financial adaptations and policy revisions to improve the economic viability of EVs.

The ‘Total Cost of Ownership’ emerges as the foremost challenge in the Financial and Resource barriers, significantly influenced by the high costs of batteries and limitations in manufacturing processes, as identified by Siragusa *et al.* (2022). Policymakers could implement financial incentives like tax breaks to mitigate these costs, while logistics companies might consider cost-sharing arrangements to reduce financial burdens. Concurrently, EV manufacturers are urged to streamline production and enhance research efforts to lower costs. Following closely, the ‘Maintenance Cost’ barrier highlights the scarcity of specialised EV maintenance skills, potentially increasing operational costs. Mitigation strategies include establishing dedicated maintenance facilities to manage these risks effectively, as Anosike et al. (2023) suggested.

In our study, the ‘High initial purchase cost’ (FR6) is identified as a significant barrier, with Aljohani and Thompson (2020) noting the diminished appeal of EVs due to their substantial upfront costs compared to conventional vehicles. Policymakers could mitigate this issue through grants or low-interest loans and logistics companies negotiating bulk deals with manufacturers to lower costs. Further, investment in battery technology is critical as ‘Battery Costs’ (FR2) represent a significant portion of initial expenses, necessitating enhanced research and sustainable solutions (Lebrouhi *et al.,* 2021). Additionally, improper charging practices adversely affect ‘Battery Lifespan’ (FR3), indicating the need for robust battery management systems to extend battery life and optimise charging processes (Gao *et al*., 2019; Schücking *et al.*, 2017). These strategies emphasise the importance of reducing economic barriers and enhancing technological efficacy to facilitate broader adoption of EVs in last-mile deliveries.

The widespread adoption of EVs hinges on the accessibility and cost-effectiveness of vital components such as cobalt and lithium, as highlighted by the next barrier, ‘Limited Raw Material Availability (FR1).’ Policymakers should prioritise initiatives to secure a stable supply of raw materials through diplomatic efforts and strategic partnerships (Berkeley *et al.*, 2017). Additionally, EV manufacturers should explore alternative battery chemistries that reduce reliance on scarce materials and invest in recycling technologies to recover and reuse valuable materials.

Another substantial barrier is the ‘Inadequate Infrastructure for Battery Swapping (FR4)’ (Keskin and Çatay, 2016), necessitating governmental incentives for developing such facilities and strategic partnerships between logistics companies and infrastructure providers to implement battery-swapping stations efficiently.

Finally, ‘Inventory Cost for Battery Swapping (FR5)’ underscores the financial implications of maintaining ample battery stock for swapping, thereby increasing overall costs (Kuppusamy *et al.*, 2017). Logistic companies should explore partnerships with battery manufacturers to streamline inventory management and negotiate favourable terms for battery procurement. In contrast, EV manufacturers should consider innovative financing options such as battery leasing to alleviate upfront costs for logistic companies.

Addressing these FR barriers through comprehensive financial strategies and policy support is essential. Such measures will improve the economic viability of EVs, enhancing their adoption in last-mile delivery operations by aligning practical solutions with the theoretical frameworks proposed by the DOI theory.

*5.3 Dimension 3: Operational and Technical Barriers (OT)*

OT barriers emerged as the third most significant dimension influencing the adoption of EVs in LMD. These barriers, which include limited vehicle range, prolonged charging times, and technical limitations of current EV models, echo the complexity and trialability components of the Diffusion of Innovations (DOI) theory. While Tarei *et al*. (2021) emphasised performance and consumer awareness issues in India, globally, these factors present a moderate challenge, corroborated by Morganti & Browne (2018) and Noel *et al*. (2020), who observed ongoing concerns about queuing, payload capacities, and grid anxieties that persist despite technological progress.

Our findings suggest that operational and technical issues not only reflect technological challenges but are also pivotal in shaping the integration of new technologies into LMD operations. Enhancing the trialability of EVs through pilot programs and demonstrations could significantly mitigate these barriers, offering firsthand benefits to potential users. Furthermore, OT barriers encompassing concerns about vehicle range, payload capacity, and compatibility with existing delivery operations are further validated by case analysis of a leading delivery service provider, which encountered significant logistical challenges in deploying EVs across its urban delivery routes (“*Policies to promote electric vehicle deployment – Global EV Outlook 2021 – Analysis*”, n.d.). These operational challenges highlight the intricate balance between technological advancements and the practicalities of delivery service operations.

In our study, the second notable barrier within the OT dimension is ‘Limited Range Availability (OT2),’ accentuated by Anosike *et al*. (2023) and Christensen et al. (2017). This challenge stems from the constraints of current battery technology, exacerbated by driving habits and environmental conditions that variably affect battery efficiency and vehicle range. Addressing this issue related to battery technology requires logistics companies to optimise delivery routes to accommodate the capabilities of the EV range. This strategy aligns with simplifying user experiences, as Siragusa *et al.* (2022) suggested.

The ‘Longer Charging Duration (OT1)’ barrier closely follows, highlighting the operational risks associated with extended charging periods, including freight safety and inefficient use of driver time. Pelletier *et al*. (2018) emphasise that prolonged charging times could significantly increase operational downtime, affecting the trialability of EVs in commercial settings. Adopting strategies such as fast charging and battery swapping could mitigate these effects and are recommended for policy support to enhance the practicality and attractiveness of EV adoption, effectively reducing the complexity perceived by end-users.

In our study, the ‘Range Uncertainty (OT3) barrier critically affects user experience by fostering a preference for conventional vehicles on extended trips. As Berkeley et al. (2017) highlighted, this uncertainty undermines confidence and hampers widespread EV adoption. The development of mobile applications to locate charging stations and manage reservations could significantly enhance the trialability of EVs, mitigating concerns over EV performance variability.

Another significant barrier is ‘Limited Loading Capacity (OT4)’, where the bulk and weight of EV batteries reduce cargo space, increasing operational costs (Christensen *et al*., 2017; Morganti and Browne, 2018). Logistic companies are encouraged to invest in advanced battery technologies that offer high capacity without the bulk, while manufacturers should focus on improving battery energy density. Policymakers are also advised to incentivise using lightweight materials in battery production to ease the load on logistics operations.

Addressing these OT barriers through the DOI framework—emphasising reduced complexity and enhanced trialability—can significantly improve the integration of EVs into LMD operations, effectively marrying theoretical constructs with the practical demands of the industry.

*5.4 Dimension 4: Public Policy, Perception and Market Barriers (PPM)*

In our research, *public policy, perception, and market barriers (PPM)* were ranked as the fourth most influential dimension, suggesting a modest but notable impact on decision-making within the adoption process of *EVs*. These barriers, deeply intertwined with the observability and social system components of the Diffusion of Innovations (DOI) theory, reflect the significant influence of social factors and public policies, as noted by D’Adamo, Gastaldi, and Ozturk (2023) and Asadi *et al*. (2022). While effective communication strategies can enhance EVs’ observability, supportive public policies are essential for creating an adoption-friendly environment.

Contrary to assertions by Morganti and Browne (2018) that emphasise the critical role of operator perceptions, our findings suggest these are just one aspect of a broader spectrum of influences, including technological and infrastructural advancements. This insight aligns with Aungkulanon *et al*. (2023), contrasting with Merky *et al*. (2016) and Quack *et al*. (2016), who focus on economic and policy challenges as significant barriers. Our research underscores the importance of a sophisticated approach to understanding barriers, highlighting the necessity for strategies that tackle social perceptions and concrete infrastructural challenges to enable the broad adoption of electric vehicles in last-mile deliveries. Consequently, it is vital to critically navigate the evolving landscape of policy decisions when assessing electric vehicles’ sustainability in these operations. Effective policy frameworks must be adaptive and forward-looking, integrating technological advancements, market dynamics, and environmental priorities to ensure successful implementation and widespread acceptance.

Our study findings challenge those presented by Goel *et al*. (2021) about the critical influence of familial and policy factors on EV adoption, suggesting that the impact of these barriers varies significantly across different contexts. This finding aligns with DOI’s focus on social systems and external change agents, indicating a need for more nuanced policy approaches. Contrasting with Asadi *et al*. (2022), our research emphasises the diverse influences of environmental concerns, trust in technology, and cultural norms across various regions, underscoring the need for tailored strategies that reflect local market conditions to enhance EV adoption effectively. The findings highlight compatibility and observability’s critical role in the diffusion of innovations theory within varying geographical and cultural landscapes. The findings all illustrate the need to consider a more comprehensive array of elements within the DOI framework, such as the evolving nature of ‘compatibility’ with existing technologies and infrastructures, the ‘complexity’ of adopting new technologies, and the varying ‘observability’ of benefits across different markets. This nuanced understanding can help stakeholders formulate more effective strategies tailored to specific market needs and conditions, enhancing the effectiveness of interventions promoting EV adoption.

Moreover, policy perception and market barriers have been substantiated through interviews with industry stakeholders, revealing a perceived lack of supportive governmental policies and incentives as a critical barrier to EV adoption in last-mile deliveries *(“Barriers to electric vehicle adoption*”, n.d.). These findings reflect the crucial role of regulatory frameworks in facilitating or hindering the transition to electric mobility in logistics operations.

Our research emphasises the environmental sustainability of electric vehicles (EVs), mainly focusing on the lifecycle challenges associated with their batteries. While EVs represent a crucial strategy for decarbonising transport, producing and disposing of batteries raise significant environmental concerns. Citing D’Adamo, Gastaldi, and Ozturk (2023), our study highlights the necessity for integrating renewable energy sources, fostering local industrial advancements, and establishing robust battery recycling methods to ensure EVs genuinely benefit the green transition. It also underscores the importance of addressing the current technological, economic, and regulatory uncertainties in battery recycling, essential for reducing environmental impact and advancing sustainable practices in the industry.

The PPM dimension comprises five specific barriers, with ‘Policy and Regulatory obstacles (PPM5)’ identified as the most significant. This barrier underscores the need for robust regulatory frameworks and external support, especially in developing countries, despite substantial government advocacy in nations like Canada, China, Norway, the UK, and the US (Hosseinpour *et al*., 2015; Jones *et al*., 2020). Effective intervention necessitates developing and implementing comprehensive policies that foster EV adoption through enhanced financial incentives and stringent emission standards, thus aligning EV compatibility with existing transportation and environmental policies and increasing their attractiveness to potential users.

‘Socio-technical barriers (PPM1)’ emerge as the next significant barrier, prominently highlighting consumer apprehensions about EV technology, exacerbated by battery failures and environmental impacts (Berkeley *et al*., 2017). Overcoming these concerns necessitates robust educational initiatives that underscore the safety and reliability of EVs, complemented by stringent safety standards to bolster public trust and observability.

‘Uncertainty Over Resale Value (PPM3)’ is the third relative barrier attributed to the underdeveloped secondary market for EVs (Berkeley *et al*., 2017). Enhancing consumer confidence requires collaborative efforts to stabilise resale values through strategies such as buyback programs and incentives for trading in older models. Policy enhancements are essential, with initiatives like tax benefits for used EV purchases to foster a vibrant second-hand market.

The ‘Limited variety of models (PPM4)’ is the fourth-ranked barrier of this dimension, reflecting the market’s current shortfall in meeting diverse consumer needs across price, functionality, and style (Aungkulanon *et al.*, 2023). To overcome this barrier, EV manufacturers should prioritise significantly developing and expanding their range, supported by policy measures incentivising diversification through R&D grants and tax benefits.

Lastly, ‘Lack of Trust for Environmental Benefits’ highlights the necessity to understand the intricacies of EV sustainability. To address this, providing clear and accurate information about the environmental advantages of EVs is crucial. Policymakers should support initiatives that increase public understanding of how EVs contribute to reducing emissions, enhancing their observability and perceived ecological compatibility.

*5.5 Implications for Theory and Practice*

*Managerial and Social Implications*

This study identifies critical strategies for overcoming barriers to EV adoption in last-mile deliveries (LMD), focusing on four main dimensions: Energy and Infrastructure (EI), Financial and Resource (FR), Operational and Technical (OT), and Public Policy and Market (PPM).

*Energy and Infrastructure Barriers (EI):* Addressing EI barriers requires logistics managers to prioritise strategic planning and investment. Developing a robust charging infrastructure is essential, and implementing this involves partnerships with municipal authorities and private entities to establish charging stations along crucial delivery routes and depots. Fast-charging options are vital to minimise downtime, whereas collaboration with utility companies to upgrade grids and integrate smart-grid technologies will ensure sufficient power for increased EV use. Investment in renewable energy is also necessary to enhance sustainability and reduce reliance on traditional power sources.

Companies must work closely with EV manufacturers to develop vehicles suited for LMD needs, including the appropriate range, payload capacities, and infrastructure compatibility. Policy advocacy is crucial to securing supportive regulations, incentives, and infrastructure development for EV adoption. Conduct risk assessments to mitigate disruptions from power or infrastructure failures and use demonstration projects to showcase EVs’ operational and environmental benefits.

*Financial and Resource Barriers (FR):* Managing the high initial costs of EV adoption requires innovative financing solutions. Tax incentives, grants, and cost-sharing programs can reduce ownership costs and make EVs more competitive. Managers should explore options such as battery leasing and Vehicle-as-a-Service (VaaS) to spread the financial burden over time. These models help distribute costs and accelerate large-scale EV adoption.

Collaboration with battery manufacturers is essential for managing the costs of maintaining a battery stock for swapping. These partnerships can help secure favourable procurement terms and reduce inventory costs. Advancements in battery technology, remarkably increasing battery life, can further reduce replacement costs and improve overall cost efficiency. Fleet operators should implement battery management systems to optimise charging, prevent overcharging, and maximise battery longevity. Additionally, comprehensive driver training on optimal EV usage and charging practices will minimise wear and tear, ultimately reducing maintenance costs.

*Operational and Technical Barriers (OT):* Overcoming OT barriers requires targeted operational adjustments. Advanced route optimisation software is critical to improving operational efficiency, while selecting EV models with appropriate range capabilities can help address range limitations. Upgrading the charging infrastructure and integrating telematics systems to track EV performance will improve fleet management. Predictive maintenance technologies can minimise downtime by addressing issues before they escalate.

Companies should invest in redundant charging solutions such as mobile units or backup generators to ensure uninterrupted operations. Pilot trials are a practical way to test EV strategies, gather data, and refine operational processes under real-world conditions. Developing specialised training programs for technical staff and creating emergency response strategies, including EV-specific roadside assistance, are vital for maintaining robust EV operations.

*Public Policy and Market Barriers (PPM):* Regulatory frameworks and market dynamics play a critical role in the adoption of EVs. Companies should engage with policymakers to secure favourable policies, subsidies, and tax incentives that promote EV integration. Public-private partnerships are vital to accelerating the development of the necessary infrastructure.

Building a solid secondary EV market is also crucial. Logistics companies should work with policymakers to create initiatives like buyback programs and trading incentives to enhance the attractiveness of EV investments. Additionally, investing in educational campaigns that raise public awareness of EVs’ environmental and economic benefits is essential to dispelling misconceptions and boosting acceptance.

*Theoretical Implications*

This study contributes significantly to extending the *Diffusion of Innovations (DOI)* theory by addressing how systemic barriers influence the adoption of EVs in LMD. This research systematically categorises barriers aligned with DOI, highlighting its potential to evolve into a more predictive model for assessing the likelihood of successful technological adoption. Enhancing DOI to incorporate predictive capabilities across various industrial environments would significantly advance its utility for understanding technology adoption processes.

The interaction of diverse barriers calls for expanding DOI’s theoretical scope. Incorporating insights from ecological modernisation and resource-based theories can provide a more robust framework for examining the interplay between environmental benefits, economic viability, and organisational capabilities. This integration would enrich DOI, offering a more comprehensive view of how innovations proliferate within complex socio-economic ecosystems, especially for sustainable technologies like EVs.

A key finding is the significant influence of *Energy and Infrastructure (EI)* barriers on EV adoption in logistics. These findings suggest that the DOI model must evolve to better account for systemic compatibility and the readiness of existing infrastructure. To make DOI more applicable to modern technological innovations, future research should develop methodologies that address complexities and trialability challenges, primarily focusing on how infrastructure modifications influence EV adoption. On the other hand, the study also identifies *Financial and Resource (FR)* barriers as the second most critical dimension affecting EV adoption. To better reflect these barriers, DOI should refine its constructs of “relative advantage” and “economic compatibility.” By incorporating factors such as fluctuating material costs, evolving financial incentives, and the high initial expenses related to EV adoption, DOI can better understand how economic considerations impact the uptake of innovations. Future research should explore how these dynamic economic factors influence the perceived advantage of EVs over traditional vehicles.

The *Operational and Technical (OT)* barriers highlight the need for DOI to account for complexity and trialability more nuancedly. Adoption models should incorporate operational realities, such as vehicle range limitations and charging infrastructure inefficiencies, to better explain how technological innovations are integrated into complex logistical systems.

Lastly, while *Public Policy and Market (PPM)* barriers were the least influential in this study, they offer a critical opportunity for enhancing DOI. Incorporating the role of regulatory frameworks, policy incentives, and geographical and cultural factors would allow DOI better to predict the adoption of sustainable technologies across diverse contexts.

**6. Conclusions**

This study explored the barriers to adopting electric vehicles (EVs) in last-mile deliveries, a critical component for sustainable transportation.

From a theoretical perspective, the study embarks on an innovative journey by evaluating and categorizing 21 barriers to EV adoption into four distinct dimensions, utilizing EFA. The subsequent employment of the AHP facilitated the determination of global weights and ranks of these barriers, an aspect notably absent in existing literature concerning last-mile operations.

Practically, this research furnishes stakeholders with a foundational list, enabling them to prioritize various barriers—spanning energy, infrastructure, financial, resource, operational, technical, policy, perception, and market dimensions—by ranking specific barriers under these categories. Further, it proffers pragmatic recommendations for stakeholders to navigate through the identified, validated, categorized, and ranked barriers, facilitating a smoother adoption of EVs in last-mile operations. Furthermore, this research underscores the multifaceted transition to sustainable transport solutions, necessitating a collaborative effort among policymakers, industry stakeholders, and technology providers to overcome these barriers effectively.

Through the application of Exploratory Factor Analysis (EFA) and the Analytical Hierarchy Process (AHP), we identified and prioritized four main categories of barriers: Energy and Infrastructure Barriers (EI), Financial and Resource Barriers (FR), Policy Perception and Market Barriers (PPM), and Operational and Technical Barriers (OT). As revealed through our analysis, the paramount barrier lies within the Energy and Infrastructure realm, emphasizing the urgent need for enhanced charging infrastructure and energy supply frameworks to support EV adoption. This barrier is closely followed by Financial and Resource Barriers, highlighting the significant investment requirements and economic considerations companies face when integrating EVs into their fleets. Operational and Technical Barriers and Policy Perception Market Barriers also play substantial roles, pointing to the need for technological advancements and supportive policy frameworks to facilitate a smoother transition to EV usage in last-mile deliveries.

*Limitations and Future Research Directions*

This study provides a detailed examination of the barriers to adopting electric vehicles (EVs) in last-mile deliveries, identifying several limitations that may affect the robustness and generalizability of the results. The primary constraint arises from reliance on convenience sampling of 157 supply chain experts. Although efficient, this method may not adequately represent the diversity of logistics scenarios and geographic regions, potentially skewing results towards those already familiar with or interested in EV technologies and possibly overlooking perspectives from smaller enterprises or less developed markets.

The geographical diversity within the sample also poses limitations. Most experts consulted may share similar regional experiences, potentially reflecting biases based on their predominant market operations. These limitations could restrict the applicability of the findings to other regions that the sample does not adequately represent, thus affecting the study's global relevance. Future research should utilize more robust sampling methods, such as stratified or random sampling, to enhance the representativeness of the findings.

Methodologically, integrating EFA and AHP to categorise and rank barriers introduces specific constraints. EFA depends heavily on the initial choice and the number of factors that could influence the outcomes. AHP, while providing a structured decision-making approach, might introduce subjectivity through its pairwise comparison process, primarily as it relies on expert judgments that can be inherently biased. Moreover, applying AHP’s local-global priority approach may inadvertently introduce biases due to uneven criteria distribution across categories. This uneven criteria distribution could dilute or prioritize criteria weights not based on their intrinsic importance but on the relative number of elements requiring prioritization. Future investigations might benefit from integrating additional decision-making frameworks, such as the Delphi method or alternative multi-criteria decision-making (MCDM) techniques. These methods could provide a balanced approach to criteria weighting, potentially offsetting the limitations identified within the AHP framework.

In this study, while we employed validated methodologies such as AHP and EFA to identify and analyze barriers to EV adoption, we did not conduct a sensitivity analysis to test the robustness of these findings. Future research should integrate sensitivity analysis to bolster the validity of the findings and explore how modifications to the analyzed barriers could affect the proposed solutions. Further, sensitivity analysis can elucidate the relative importance of the different obstacles under varying scenarios, pinpointing critical barriers and opportunities within EV adoption processes. This approach would enhance the understanding of the barrier dynamics and provide a stronger empirical foundation for making strategic decisions to facilitate EV adoption in LMD.

The scope of the study spans all EV types without delving into the nuanced differences among them. Additionally, the barriers identified reflect the current state of technology and market conditions, subject to rapid changes. Advances in EV technology and shifts in regulatory landscapes could soon render some identified barriers outdated, suggesting that the findings may require periodic updates to remain pertinent.

Further, while the study identifies and ranks barriers broadly, it does not delve deeply into the specific underlying causes of each barrier. For instance, although acknowledged but not explored in detail, issues such as the role of government policy, mainly how policy variations between countries specifically affect EV adoption in last-mile deliveries. The research primarily focuses on technical and infrastructural aspects, with less emphasis on the economic or political factors that significantly influence technology adoption.

Future studies should adopt a more integrated approach considering these dimensions to provide a more comprehensive understanding of the barriers to EV adoption. Researchers also need to engage more deeply with the complexities of battery recycling and the effects of policy shifts. More studies must explore integrating EVs with renewable energy sources to fulfil sustainability goals. Future research must investigate sustainable models for battery lifecycle management and understand the dynamic implications of policy choices on EV adoption.

Future inquiries should aim to provide a comprehensive view of barriers across different geographical, cultural, economic, and environmental contexts. They should employ mixed methods and longitudinal designs to capture the evolving nature of these obstacles. Incentive schemes and policy interventions across varied policy landscapes represent another crucial area for exploration, potentially informing strategies to enhance EV adoption rates and sustainability outcomes. Additionally, understanding consumer and stakeholder perceptions through psychological and sociological analyses will be vital in addressing the motivational and attitudinal drivers behind EV adoption in last-mile deliveries.

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