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Enhancing Sustainable Last-Mile Delivery: The Impact of Electric Vehicles and AI Optimization on Urban Logistics

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Abstract: The rapid growth of e-commerce has intensified the need for efficient and sustainable last-mile delivery solutions in urban environments. This paper explores the integration of electric vehicles (EVs) and artificial intelligence (AI) into a combined framework to enhance the environmental, operational, and economic performance of urban logistics. Through a comprehensive literature review, we examine current trends, technological developments, and implementation challenges at the intersection of smart mobility, green logistics, and digital transformation. We propose an operational framework that leverages AI for route optimization, fleet coordination, and energy management in EV-based delivery networks. This framework is validated through a real-world case study conducted in Lisbon, Portugal, where a logistics provider implemented a city consolidation center model supported by AI-driven optimization tools. Using key performance indicators—including delivery time, energy consumption, fleet utilization, customer satisfaction, and CO_2 emissions—we measure the pre- and post-AI deployment impacts. The results demonstrate significant improvements across all metrics, including a 15–20% reduction in delivery time, a 10–25% gain in energy efficiency, and up to a 40% decrease in emissions. The findings confirm that the synergy between EVs and AI provides a robust and scalable model for achieving sustainable last-mile logistics, supporting broader urban mobility and climate objectives.

Keywords: sustainable last-mile delivery; electric vehicles (EVs); urban logistics; artificial intelligence (AI)

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1. Introduction

The explosive growth of e-commerce has reshaped consumer expectations and transformed the logistics industry, especially in last-mile delivery. The last-mile delivery process, which encompasses the transportation of goods from a distribution center to the end consumer's doorstep, represents a critical juncture in contemporary supply chain management, significantly impacting customer satisfaction, operational costs, and environmental sustainability [1,2]. Urban centers, characterized by high population density, traffic congestion, and limited space, pose formidable challenges to efficient last-mile operations, leading to increased delivery times, elevated transportation costs, and amplified emissions. The pursuit of sustainable last-mile solutions demands a holistic approach that considers not only economic viability but also environmental and social implications, often referred to as the "triple bottom line of sustainability" [3]. Studies show that last-mile delivery can constitute up to 53% of total shipping costs, owing to the need for speed, accuracy, and flexibility in urban environments [4]. Furthermore, the heavy reliance on traditional combustion-engine vehicles for these deliveries significantly contributes to urban congestion, air pollution, and greenhouse gas emissions, presenting a serious environmental concern as cities strive to meet sustainability goals. In response, electric vehicles (EVs) are gaining momentum as an environmentally friendly solution for last-mile delivery, offering reduced emissions, quieter operations, and potential cost savings over the vehicles' lifespans. However, despite their advantages, the widespread adoption of EVs in logistics faces several obstacles, including limited battery range, charging infrastructure constraints, and high initial costs. Addressing these challenges requires not only advancements in EV technology but also innovative management strategies that leverage artificial intelligence (AI). AI-powered tools can enhance the efficiency of last-mile delivery with EVs by optimizing routes, predicting energy consumption, and enabling real-time fleet management. Through machine learning and predictive analytics, AI can help logistics providers overcome the logistical limitations of EVs, such as range anxiety and charge scheduling, by dynamically adapting routes based on traffic, weather, and battery status. This synergy between EVs and AI holds promise for transforming last-mile logistics into a more sustainable and economically viable practice. This paper investigates the integration of EVs and AI in last-mile delivery, evaluating their environmental impact, economic feasibility, and operational challenges. By examining case studies and analyzing current data, we aim to present a comprehensive view of how EVs and AI can drive sustainability in urban logistics and identify the steps necessary to overcome existing barriers to their widespread adoption. The findings suggest that while EVs and AI each present unique advantages, their combined use offers a robust framework for achieving sustainable last-mile logistics in cities worldwide.

Addressing the multifaceted challenges inherent in last-mile logistics necessitates a comprehensive understanding of the distinct perspectives and constraints of key stakeholders, encompassing municipalities, transportation companies, retailers, and consumers. Municipalities grapple with the dual mandate of fostering economic growth and ensuring sustainable urban development, navigating the delicate balance between facilitating commercial activities and mitigating the adverse impacts of increased delivery traffic, such as congestion, noise pollution, and air quality degradation.

The conventional approaches to last-mile delivery, often characterized by a reliance on traditional vehicles and fragmented delivery networks, are proving inadequate in the face of escalating demand and increasing urban congestion. Therefore, it necessitates the exploration of alternative delivery models, such as the utilization of electric vehicles, cargo bikes, and drones, coupled with the implementation of consolidated delivery networks and optimized routing algorithms, to mitigate the environmental impact and enhance operational efficiency. The logistics hubs have played an important role in traditional delivery solutions, but the application of Industry 4.0 inventions has made it possible to redefine the hub and spoke of a centralized transport topology optimization paradigm [5]. These technological advancements, such as real-time tracking, predictive analytics, and autonomous delivery systems, hold immense potential for transforming last-mile logistics, improving visibility, reducing costs, and enhancing the overall customer experience [6].

One of the primary challenges is the diversity of delivery requirements, as transporting various types of goods demands customized logistical approaches, increasing operational complexity. Urban congestion further exacerbates these challenges, making deliveries in densely populated areas more time-consuming and costly while also raising safety concerns.

Effective public–private partnerships, as well as the incorporation of technology, are essential for achieving environmental sustainability within the transportation sector [6]. Policy recommendations aimed at fostering a more sustainable and efficient urban delivery ecosystem encompass a range of measures, including the implementation of congestion pricing, the establishment of urban consolidation centers, the promotion of electric vehicle adoption, and the development of standardized data sharing platforms. Urban Consolidation Centers (UCCs) have the potential to reduce traffic congestion, lower emissions, and improve delivery efficiency by centralizing the distribution of goods in urban areas [7]. However, their successful implementation often depends on voluntary participation from logistics providers, which can limit their effectiveness. As a result, governmental support—through incentives, regulation, or public–private partnerships—is usually necessary to ensure widespread adoption and long-term viability [8]. By incentivizing the use of alternative delivery modes, streamlining regulatory processes, and fostering collaboration among stakeholders, municipalities can play a pivotal role in shaping the future of last-mile logistics, creating urban environments that are both economically vibrant and environmentally sustainable.

Building on these challenges, this paper emphasizes the role of advanced technologies, particularly artificial intelligence (AI), in optimizing logistics. The integration of artificial intelligence can enhance route planning, enable real-time tracking, and improve overall efficiency. Alternative delivery methods, such as the use of autonomous vehicles, drones, and centralized locker systems, offer solutions to mitigate logistical bottlenecks. By adopting these innovations, businesses can meet increasing consumer demands and maintain a competitive advantage in the evolving logistics landscape.

Recent shifts in sustainability thinking have emphasized not only emission reductions, but also the circular economy, environmental justice, and systemic resilience [9,10]. In the context of logistics, this translates into a push for low-impact urban delivery systems that minimize congestion, promote equity in service access, and align with broader Smart City and Sustainable Development Goals (SDGs) [11]. Meanwhile, logistics innovation is evolving beyond digital tracking to embrace real-time data ecosystems, micro-fulfillment networks, and decentralized warehousing strategies [12,13]. On the technology front, artificial intelligence in logistics is maturing, moving from static optimization tools to adaptive, self-learning systems capable of real-time decision-making, anomaly detection, and energy-aware routing [14,15]. These emerging concepts challenge the sector to integrate technological advances with sustainable urban development, which this paper addresses by exploring the convergence of AI and electric vehicles in the last-mile delivery context.

While numerous studies highlight the potential of electric vehicles (EVs) and artificial intelligence (AI) in addressing these challenges, contributions often remain fragmented and theoretical, lacking real-world validation or integrative perspectives. This paper addresses that gap by presenting a comprehensive framework—ECO.Logística—that combines EV deployment and AI-driven optimization within a city consolidation center (CCC) model. We further validate this framework through a real-world case study in Lisbon, Portugal, offering measurable performance improvements across key operational, environmental, and customer satisfaction indicators.

The contributions of this study are fourfold: (1) we synthesize current trends in AI- and EV-enabled last-mile logistics and identify key limitations in the literature; (2) we propose a practical, scalable operational framework that integrates these technologies; (3) we validate the framework using pre- and post-deployment data from an active logistics operator; and (4) we offer a critical discussion of implementation challenges, trade-offs, and future research pathways.

By combining conceptual insights with empirical validation and a reflective discussion of real-world barriers and ethical implications, this paper contributes a unique and actionable model for sustainable last-mile delivery.

2. Literature Review

This study adopts a structured literature review methodology to explore the integration of electric vehicles (EVs) and artificial intelligence (AI) in last-mile logistics. The review process followed three main stages: (1) literature identification, (2) screening and selection, and (3) synthesis and thematic categorization.

The search was conducted across two major scientific databases: Scopus and Web of Science (WoS). Keywords used included combinations such as “last-mile delivery”, “urban logistics”, “electric vehicles”, “artificial intelligence”, “route optimization”, and “sustainability”. The time frame was restricted to publications from 2018 to 2025 to capture recent technological and policy developments.

After applying the inclusion criteria—peer-reviewed journal articles written in English and directly addressing AI or EV applications in last-mile logistics—a total of 78 articles were selected. Each article was reviewed and coded based on its research focus, methodological approach, contribution type (conceptual, empirical, or technical), and geographic relevance. A thematic synthesis was then conducted to identify trends, research gaps, and opportunities for integrating AI and EVs into sustainable logistics.

Electric vehicles (EVs) present significant environmental benefits for last-mile delivery in urban logistics. They offer lower operating costs and are more economical than fossil fuel-based internal combustion engine (ICE) vehicles, such as traditional diesel or petrol vans, particularly in urban delivery contexts. Beyond cost savings, EVs contribute to reducing environmental and noise pollution while promoting energy efficiency, making them a sustainable alternative for urban logistics [16]. The shift toward EVs in last-mile delivery is expected to generate a positive environmental impact, especially with extended vehicle lifespans and an increase in delivery frequency [17].

Artificial intelligence (AI) has the potential to enhance the efficiency of last-mile delivery by addressing the sustainability and service challenges of Urban Last Mile Logistics (ULMLs). AI improves demand forecasting, optimizes tour and route planning, and enhances digital delivery assistance, leading to greater efficiency in operations [18]. AI implementation in ULMLs planning and execution has demonstrated the potential to significantly enhance service quality, though challenges such as high investment and operational costs must be addressed [18]. Additionally, AI integration with EVs seeks to optimize efficiency, lower costs, and improve customer satisfaction. Expected impacts include reduced parking issues, decreased traffic congestion, and better energy conservation [19].

The integration of electric vehicles (EVs) with AI-driven technologies differs fundamentally from autonomous vehicle systems. AI-driven EV integration focuses on optimizing vehicle performance, efficiency, and management through technologies such as predictive maintenance, intelligent route optimization, battery management, and fleet coordination. These enhancements support human drivers and fleet operators by improving decision-making and operational efficiency without eliminating human control. In contrast, autonomous vehicles are designed to operate without human intervention, relying on advanced perception systems, real-time navigation algorithms, and autonomous decision-making models. While both approaches leverage artificial intelligence, AI-driven EV integration enhances existing transportation systems, whereas autonomous vehicles aim to replace human-driven operations entirely.

Despite the benefits, implementing electric vehicles in last-mile delivery comes with notable challenges and limitations. The cost of electric vans, the underdeveloped technological advancements in van batteries, and the need for improved energy infrastructure are key hurdles that must be overcome [20]. Operational constraints such as the restricted driving range of EVs and the necessity for mid-route recharges require careful logistics planning to maintain efficiency [21]. Furthermore, the limited range of EVs and the unpredictability of traffic conditions create additional challenges that need to be addressed to optimize energy use and delivery performance in urban environments [22].

The use of AI optimization in last-mile delivery also raises ethical concerns. Safety measures and compliance with regulations for autonomous vehicles must be prioritized, while the impact of AI on job roles and potential labor shortages needs to be carefully managed [23]. Additionally, the acceptance of EVs for last-mile delivery by drivers is influenced by factors such as environmental concerns, perceived ease of use, and overall user experience. Addressing both the ethical and practical considerations is essential to ensure the successful adoption of new technologies in last-mile delivery operations [24].

Therefore, the use of electric vehicles for last-mile delivery in urban logistics offers environmental benefits such as reduced pollution and energy savings, while AI optimization has the potential to significantly improve efficiency and service quality. However, challenges such as high investment costs and ethical considerations related to the adoption of new technologies need to be carefully addressed to ensure sustainable and ethical last-mile delivery practices.

3. Sustainable Urban Logistics and Smart Cities

The integration of sustainable urban logistics and smart city initiatives is an emerging research focus that addresses the pressing need for low-carbon, efficient last-mile delivery systems. Across the reviewed literature, several thematic clusters emerge, revealing both conceptual richness and practical limitations.

Location optimization and network design form one core research strand. Studies such as [25,26] present multi-objective models for optimizing pick-up points and hub placement. These approaches offer valuable contributions to urban spatial efficiency but often remain constrained by idealized assumptions and limited real-world validation. Similarly, GIS-based methods [27] offer promising avenues for network planning, though they rarely consider social or political constraints like zoning laws or community impact.

Sustainability frameworks and best practices are another central theme, with papers like [28–30] providing reviews and taxonomies to guide eco-efficient logistics design. While these works help structure the field and define key metrics, they are largely conceptual and sometimes detached from implementation challenges, especially in rapidly urbanizing or under-resourced regions. Moreover, there is a tendency to focus narrowly on emissions and cost metrics, without sufficient attention to equity, resilience, or systemic effects.

A third thematic cluster involves the role of emerging technologies—particularly AI, IoT, robotization, and platform-based logistics systems. Contributions like [31–33] discuss the potential for real-time tracking, automation, and adaptive systems to improve last-mile operations. However, these studies often prioritize technical feasibility over socio-technical integration, neglecting challenges like workforce transformation, digital infrastructure readiness, and regulatory alignment. Similarly, the smart city–logistics integration discussed in [32,34,35] tends to assume interoperability across systems that may not yet be standardized.

Some papers push the envelope with futuristic logistics models, including autonomous maritime delivery [36], scenario modeling for 2035 [37], and loosely coupled logistics platforms [35]. These works demonstrate imaginative thinking, but their speculative nature means they offer limited guidance for current policy or business decision-making. What is often missing is a bridge between these visionary ideas and short-term implementation pathways.

Finally, risk assessment and governance appear in a few studies [38,39], which identify the complexity of coordinating multiple stakeholders and the hidden hurdles in e-commerce delivery. Yet, few papers offer robust strategies for navigating public–private collaboration, or for managing conflicting interests in urban freight planning.

In summary, the literature demonstrates a growing interest in smart, sustainable logistics solutions—but is marked by fragmentation, an over-reliance on conceptual models, and insufficient empirical grounding. Very few studies examine the combined role of AI and EVs within existing logistics ecosystems, and they do not systematically evaluate the trade-offs between technological innovation and governance capacity. This gap underscores the relevance of developing integrative frameworks—such as ECO.Logística—that consider technological, operational, and institutional dimensions in unison.

4. Electrification of Last-Mile Delivery Fleets

Electrifying last-mile delivery fleets is a growing research domain, reflecting the increasing pressure to decarbonize urban freight systems while maintaining service efficiency. The reviewed literature [27–53] spans economic modeling, vehicle routing algorithms, fleet management, infrastructure planning, and adoption barriers—revealing both technological advances and persistent challenges in implementing electric vehicle (EV) solutions.

One major cluster of studies addresses the technical and economic feasibility of electrification in different contexts. Papers like [17,40,41] develop models for evaluating the operational impact and cost-efficiency of EV adoption, with [40] specifically proposing long-term planning strategies for mixed fleets of electric and internal combustion engine vehicles (ICEVs). These models provide valuable quantitative insights but often lack integration with real-world constraints, such as local electricity infrastructure or regulatory dynamics. The optimization of vehicle routing for electric fleets is also extensively studied in [19,42,43], where algorithmic approaches consider time windows, customer satisfaction, and fleet heterogeneity. While computationally robust, many of these models still rely on assumptions about static demand and predictable charging patterns, limiting their scalability.

Several works take a strategic and planning-focused perspective. For instance, ref. [44] addresses the siting of EV charging stations, while [45] proposes fleet management strategies that align with sustainability goals. The electrification of postal and parcel fleets, including the infrastructure implications and emissions impact, is thoroughly analyzed in [46], which offers a rare systems-level approach that integrates logistics routing with energy grid models. However, these strategic contributions often assume policy support and grid readiness that may not yet exist, especially in emerging economies.

The literature also explores context-sensitive solutions, particularly in constrained environments. For example, ref. [47] examines the deployment of light electric freight vehicles (LEFVs) in Quito's historic district, balancing logistics efficiency with heritage preservation. Similarly, refs. [33,48,49] propose technological innovations—such as IoT systems, E-axle retrofitting, and hydrogen vehicle simulations—to support electrification for different fleet sizes and terrains. While technically insightful, these studies rarely address broader organizational change, or the cross-sector collaboration needed for actual deployment.

Barriers to adoption and user acceptance are recurring themes, highlighted in [24,50–52], which includes the study of both managerial- and driver-level resistance. These papers emphasize psychological and operational hurdles—such as range anxiety, a lack of charging infrastructure, and perceived performance gaps—but tend to stop short of proposing systemic interventions or behavior change strategies. Studies from specific regions, like [50] in Finland, [24] in Türkiye, and [53] in China, contribute useful case-specific insights but are difficult to generalize across diverse urban contexts.

In terms of policy and business model innovation, refs. [22,54,55] discuss investment strategies, integration platforms, and small business applications for electrified last-mile logistics. These studies highlight the importance of financial incentives and innovative service designs but often lack a quantitative analysis of the returns on investment or policy impacts. Meanwhile, refs. [56,57] tackle electrification in the context of broader smart city goals, identifying both structural enablers and governance-related challenges.

A final set of studies provides comprehensive or forward-looking assessments, notably, refs. [57,58]. These authors offer literature reviews and research agendas, identifying trends, gaps, and future directions. Refs. [49,59] use simulation-based methods to assess electrification outcomes, offering high-level scenario modeling but limited real-world validation. The environmental trade-offs, including emissions savings and grid impacts, are explored in [46], which stands out because it links delivery fleet electrification to smart charging strategies and decentralized distribution models.

Collectively, the reviewed studies demonstrate significant progress in modeling, planning, and evaluating electric vehicle deployment in last-mile delivery. However, they also reveal persistent fragmentation—particularly a lack of integration across energy, mobility, and urban governance systems. Most papers focus on one dimension (e.g., routing, technology, or behavior) but few present holistic strategies for scaling EV adoption in complex, real-world logistics environments. Additionally, there is limited empirical work assessing actual EV deployment outcomes in cities, suggesting a need for cross-sectoral pilots and longitudinal studies. This reinforces the relevance of comprehensive frameworks like ECO.Logística, which aim to combine technological innovation with strategic planning and sustainable governance.

5. AI-Driven Urban Logistics

The growing integration of artificial intelligence (AI) in urban logistics is reshaping how delivery systems are planned, managed, and optimized. Across the reviewed literature, AI is framed not only as a tool for operational efficiency, but also as a catalyst for building smarter, more sustainable logistics ecosystems. However, while the potential is widely acknowledged, challenges remain in scalability, data governance, real-world integration, and impact validation.

A key area of consensus is the use of AI for route optimization and predictive logistics. Studies such as [60,61] explore machine learning techniques to streamline routing, predict delivery times, and reduce energy usage. A notable exception is the work that introduces a Pareto-optimal path generation algorithm for stochastic transportation networks [62]. By incorporating travel time variability and using simulation-based methods rather than assuming fixed probability distributions, their approach offers a more realistic foundation for AI-powered route planning when there is uncertainty.

AI's contribution to sustainable logistics is highlighted in works like [63,64], which link AI integration to broader environmental goals. These studies emphasize AI's role in enabling green logistics, offering models that reduce emissions and support sustainable transport planning. While this aligns well with smart city strategies, the environmental claims often lack lifecycle assessments or detailed analyses of energy inputs versus AI system outputs—particularly when the AI models require intensive data processing.

The intersection of AI, IoT, and electric vehicles is another emerging area, as explored in [65]. This paper proposes adaptive control techniques that combine AI and IoT for optimizing EV performance, battery management, and real-time fleet coordination. This study is notable for addressing the physical constraints of EVs in logistics operations, but like many technology-driven studies, it assumes a level of digital maturity and infrastructure availability that may not reflect current urban realities—especially in cities with uneven digital development. In parallel, infrastructure-level applications of AI—such as intelligent sensor placement for urban traffic flow identification—are gaining traction. For instance, the recent work [66] introduces an optimization framework to strategically place traffic sensors in large-scale networks, enabling precise path flow identification. This kind of real-time data infrastructure could greatly enhance the performance of AI-driven logistics systems by supplying more accurate and granular traffic inputs to routing algorithms. Similarly, ref. [67] employ Deep Residual Neural Networks combined with a variance-based sensitivity analysis to model red light crossing violations, revealing how traffic signal parameters and intersection design influence driver behavior. Therefore, this approach highlights AI's potential to enhance both safety and policy design in urban mobility systems.

Papers such as [68,69] take a broader view, analyzing collaborative logistics systems and trends in AI research. Ref. [68] discusses the role of urban freight analytics and data sharing in enabling coordinated deliveries and reducing redundancy. Ref. [69] provides a meta-level overview of AI trends in transport and logistics, identifying common challenges such as lack of standardization, difficulty in cross-platform integration, and limited public-sector adoption. While both studies offer valuable thematic insights, they stop short of presenting actionable frameworks or assessing governance implications, such as data privacy or platform monopolization risks.

Despite its promise, AI integration in logistics remains challenged by factors such as algorithmic bias in decision-making (e.g., service prioritization based on profitability), the economic burden of deploying and maintaining AI systems at scale, and the complexity of integrating AI tools with existing supply chain infrastructure [70,71]. Legacy IT systems, diverse fleet types, and varying levels of digital readiness among operators continue to pose barriers to seamless AI adoption [72]. These challenges highlight the need for inclusive design, governance oversight, and modular AI architecture that can adapt to diverse operational contexts.

Overall, the literature paints a picture of AI as a highly promising but under-integrated component of urban logistics. While many studies show clear efficiency gains at the algorithmic level, there is a lack of systemic assessments—particularly of how AI tools interact with policy frameworks, human decision-makers, or environmental objectives. There is also minimal exploration of the unintended consequences such as algorithmic bias in delivery prioritization or over-optimization that sacrifices resilience for efficiency. As urban logistics becomes increasingly complex and interconnected, future research must bridge these gaps by focusing on real-world implementation, cross-sector governance, and long-term impact evaluations—an approach that the ECO.Logística framework aims to advance.

6. Framework Proposal and Case Study Validation: AI-Optimized Last-Mile Logistics via Consolidation Centers

This section presents a practical framework, ECO.Logística, for AI-optimized last-mile delivery using city consolidation centers, followed by a case study in Lisbon that validates the approach through real-world implementation and a performance evaluation. The approach involves the use of large vans for bulk transportation to the CCC, followed by the deployment of small electric vehicles (EVs) for efficient urban distribution during the day. Artificial intelligence (AI) is employed to optimize delivery routes, monitor charging processes, and track the delivery process. Additionally, a notation tool is used to collect customer feedback, enhancing future operations and improving real-time tracking and notifications.

6.1. Operational Framework

The operational framework consists of the following:

1. A City Consolidation Center (CCC): the CCC acts as a central hub where goods are received in bulk via large vans, reducing congestion and pollution in urban areas.

2. Electric Vehicle Deployment: small EVs are dispatched from the CCC for last-mile delivery, ensuring sustainable and efficient transportation.
3. AI Optimization: AI algorithms optimize delivery routes based on real-time traffic, weather conditions, and delivery schedules, reducing delays and operational costs.
4. Charging Process Monitoring: AI tracks the battery status of EVs, schedules charging times, and prevents operational disruptions.
5. Delivery Process Tracking: AI-driven tools monitor the status of deliveries, providing real-time insights to fleet managers and ensuring timely distribution.
6. Customer Feedback Collection: a notation tool is integrated to collect customer ratings and feedback, which informs future operational adjustments.
7. Client Notifications: AI-driven alerts provide customers with estimated delivery times, real-time tracking, and proactive updates on delays or issues.

6.2. Baseline for Measuring AI Savings Effect

To effectively quantify the impact of artificial intelligence (AI) on last-mile delivery operations, it is essential to establish a comprehensive baseline using a set of key performance indicators (KPIs). These metrics allow for a clear comparison of operational efficiency and sustainability outcomes before and after the integration of AI technologies.

One of the primary indicators is delivery time efficiency, which evaluates the average delivery time per package. This metric reflects the effect of AI-driven route optimization on reducing travel times and enhancing overall responsiveness. In addition, fuel and energy consumption are critical metrics, comparing the fuel usage of conventional large vans with the energy consumed by electric vehicles (EVs), both with and without AI intervention. This comparison helps assess the efficiency gains achieved through intelligent scheduling and energy management.

Fleet utilization rate is another important KPI, capturing how effectively the vehicle fleet is deployed. It includes an analysis of idle times, and the number of trips completed, offering insights into how AI improves resource allocation. Operational costs, including those associated with maintenance, fuel, labor, and EV charging, are also monitored to evaluate potential cost savings resulting from optimized logistics operations.

Environmental performance is measured through reductions in CO_2 emissions, attributable to both the adoption of EVs and the efficiency of AI-optimized delivery routes. Customer satisfaction is assessed via a dedicated index based on customer ratings and feedback, allowing for the identification of improvements in user experience following AI implementation. Lastly, the frequency of failed or delayed deliveries is tracked to determine how AI contributes to improved reliability and service consistency.

Therefore, these baseline metrics provide a robust framework for evaluating the tangible benefits of AI integration in last-mile logistics, serving as a foundation for the comparative analysis presented in this case study.

6.3. Specific Case: Urban Logistics Provider in Lisbon

To validate the effectiveness of AI-powered optimization in last-mile delivery, this case study focuses on a transportation company operating in Lisbon, Portugal. The company manages urban deliveries through a city consolidation center (CCC) located on the outskirts of the city. Goods are transported from regional warehouses to the CCC using large vans, and from there, the last-mile distribution is executed with small electric cargo bikes and vans, ensuring low-emission, efficient operations.

The implementation process began with a pre-AI baseline measurement, during which data were collected over a three-month period prior to the deployment of AI technologies. Key performance metrics gathered during this phase included average delivery times, fuel and energy costs, fleet usage levels, and customer satisfaction scores. This baseline served as a benchmark for evaluating subsequent improvements.

Following this, the company initiated the integration of AI systems. AI algorithms were introduced to enhance route planning, optimize vehicle scheduling, and manage charging patterns for electric vehicles. The deployment was conducted in phases, starting with 50 percent of delivery routes managed by AI systems, and gradually scaling up to full coverage. Over the next three months, post-AI implementation data were collected, focusing on delivery efficiency, fleet performance, and customer feedback. Special attention was given to delivery accuracy and responsiveness, both of which were expected to improve with AI integration.

A comparative analysis was then conducted to evaluate the operational and environmental impact of AI implementation. This included a before-and-after comparison of delivery performance, cost savings, and emissions reductions. In addition, the financial return on investment (ROI) of AI adoption was assessed to determine its economic viability.

The results indicated a clear performance improvement across several metrics. Delivery times were reduced by 15 to 20 percent, largely due to real-time AI-driven route adjustments. Energy efficiency improved by 10 to 25 percent through the optimization of charging schedules. Fleet utilization increased by 30 percent, driven by higher vehicle availability and reduced idle time. Customer satisfaction scores rose by approximately 20 percent, thanks to improved delivery tracking and timely notifications. Environmentally, the company achieved a 25 to 40 percent reduction in CO_2 emissions, attributed to fewer unnecessary trips and more effective vehicle allocation.

Overall, the Lisbon case study demonstrates that the integration of AI with CCC-based last-mile logistics not only enhances delivery performance but also supports broader sustainability and customer satisfaction goals.

The integration of AI with CCC-based last-mile delivery enhances efficiency, sustainability, and customer experience. The case study in Lisbon demonstrates that AI-driven logistics can significantly improve operational performance, reducing costs while ensuring greener and more efficient urban deliveries. Continuous feedback collection and AI-driven adjustments contribute to an adaptive and resilient logistics framework, ensuring long-term success in urban transportation operations.

7. Critical Discussion

While the results presented in this paper highlight the promising synergy between electric vehicles (EVs) and artificial intelligence (AI) in last-mile delivery, a critical examination is essential to identify the current limitations, systemic barriers, and broader socio-technical implications. This section addresses these elements and underscores the unique contribution of our Lisbon case study to the existing body of knowledge.

The literature in this domain often depends on theoretical or simulation-based models, which tend to rely on idealized assumptions such as static demand patterns, full digital infrastructure, or policy readiness [73,74]. These assumptions constrain the applicability of findings to real-world contexts. In contrast, our study contributes a rare empirical validation of AI–EV integration through an operational case study in Lisbon. This real-world implementation provides quantifiable metrics and practical insights that help bridge the gap between conceptual models and actual logistics environments.

Despite the promise demonstrated by our findings, significant barriers remain for broader adoption. High upfront investment costs, underdeveloped charging infrastructure, and fragmented digital systems are common impediments [51,75,76]. Moreover, the successful deployment of AI-driven logistics relies on robust data governance, encompassing secure data-sharing protocols and standardized platforms, which are not yet universally available [77,78]. From a human perspective, acceptance and adaptation challenges also persist, as delivery personnel and logistics managers may resist new workflows or perceive increased surveillance and reduced autonomy.

Furthermore, our study acknowledges the potential trade-offs and unintended consequences that may accompany optimization-focused technologies. For example, while automation can streamline operations, it may also contribute to workforce displacement, especially in routine planning or dispatch roles. Similarly, optimization algorithms designed for cost or time efficiency might unintentionally deprioritize service coverage in less profitable areas, raising concerns about equity and inclusiveness. Algorithmic decision-making may also introduce bias if trained on historical datasets that reflect existing disparities. These risks underscore the importance of designing human-centered AI systems, incorporating ethical oversight and inclusive design principles.

Looking forward, future research should focus on empirical pilot programs in diverse urban contexts to evaluate the generalizability of AI–EV frameworks. Longitudinal studies are also necessary to assess the enduring impact of these systems on environmental, operational, and social metrics. Comparative research across different regulatory and infrastructural settings can shed light on the context-specific factors influencing outcomes. Moreover, integrative frameworks that combine technological innovation with policy design, ethical guidelines, and human behavior analysis are critical to ensuring sustainable and equitable deployment.

In summary, this paper contributes to the literature by offering a grounded, case-based validation of AI and EV integration in last-mile delivery, addressing the current fragmentation in the field. By combining operational data with critical reflection, our study lays the foundation for more nuanced, scalable, and socially responsible innovations in urban logistics.

8. Conclusions

This study proposed and validated a conceptual framework for sustainable last-mile delivery that combines collaborative logistics models, data integration, and AI-driven optimization. By leveraging electric vehicles (EVs) and artificial intelligence (AI), the framework addresses the growing need for greener, more efficient, and responsive urban logistics systems. EVs offer substantial environmental benefits, including reduced emissions and lower noise levels, while AI contributes through real-time route planning, fleet coordination, energy management, and customer engagement. The synergy between these technologies supports both operational efficiency and climate-oriented goals.

However, the widespread adoption of this integrated approach faces key challenges. These include limited charging infrastructure, high upfront costs, range anxiety, and the need for interoperability with existing logistics systems. Additionally, the concerns around algorithmic transparency, user acceptance, and regulatory readiness for AI-based decision-making must be addressed. Our Lisbon case study illustrates that, when supported by a City Consolidation Center and guided by AI-based tools, last-mile operations can achieve measurable improvements in delivery time, energy efficiency, CO_2 reduction, and customer satisfaction.

Future research should prioritize the seamless integration of EVs within traditional logistics fleets, the development of adaptable AI systems for dynamic urban environments, and governance models that support secure data sharing and equitable service delivery. Emerging trends suggest a strong potential for AI to facilitate not only logistics optimization but also smart charging strategies, decentralized energy use, and real-time mobility management. The convergence of AI, EVs, and IoT will play a central role in shaping the future of sustainable urban logistics, contributing to smarter, cleaner, and more resilient cities worldwide.

Ultimately, the integration of AI and EVs in last-mile delivery represents not just a technological evolution, but a shift toward a more intelligent and sustainable urban logistics paradigm. By bridging the gap between digital innovation and environmental responsibility, this approach offers a pathway for cities and logistics providers to meet the dual challenge of operational efficiency and climate resilience in an increasingly complex urban landscape.

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