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Delivering by eco-friendly vehicles: an overview

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Abstract

The transition to eco-friendly vehicles in urban logistics is crucial for achieving sustainable urban development. This study presents an innovative approach by combining a systematic review of the literature with bibliometric analysis to explore the multifaceted impacts of adopting eco-friendly freight vehicles, particularly for last-mile deliveries. Using data from Scopus and the Web of Science, 264 studies were analysed to uncover emerging trends, challenges, and gaps. By focusing on environmental, economic, social, operational, and regulatory dimensions, the research identifies critical barriers and opportunities. The paper offers a comprehensive assessment framework and strategic insights for policy-makers and stakeholders to advance sustainable, inclusive, and efficient urban logistics systems.

Keywords: urban freight; urban logistics; urban goods movements; urban freight transport; city logistics; last-mile delivery; eco-friendly vehicle; electric vehicle; green vehicle; impact assessment; sustainable logistics.

1. Introduction

Urban areas, as centres of economic and social activity, depend heavily on the seamless flow of goods to sustain their operations. However, growing demand for freight transport places high pressure on urban infrastructure, exacerbating environmental degradation, traffic congestion, and social inequalities. Urban freight movements are responsible for up to 25% of CO_2 emissions and 50% of other transport related pollutants in cities, making them a critical area for intervention (Comi and Savchenko, 2021). The proliferation of e-commerce and home delivery services has further fragmented the distribution landscape, resulting in inefficient logistics operations, illegal parking, and prolonged use of public spaces (Castiglione et al., 2022; Comi and Savchenko, 2021). To address these challenges and align with the goals of sustainability and liveability, cities are increasingly focusing on implementing innovative urban logistics systems.

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Among the various strategies considered, the transition to eco-friendly vehicles, particularly for last-mile deliveries, has emerged as a pivotal approach. Electric vehicles (EVs) and cargo bikes, for example, offer significant potential to reduce greenhouse gas emissions, noise pollution, and dependence on fossil fuels. However, its widespread adoption faces challenges, including high initial costs, limited range and load capacity, insufficient charging infrastructure, and regulatory hurdles (Napoli et al., 2021a, 2021b). This study distinguishes itself by adopting an innovative approach to comprehensively assess the adoption of eco-friendly vehicles in urban logistics. By combining a systematic review of the literature with bibliometric analysis, it provides a robust, data-driven framework for understanding the multidimensional impacts of this transition. Unlike traditional studies that focus on isolated aspects, this research examines the environmental, economic, social, operational, and regulatory dimensions of eco-friendly/green vehicle adoption. Furthermore, advanced bibliometric tools are used to map thematic clusters and research trends, offering novel insights into the evolving landscape of urban logistics. By bridging the gap between academic research and practical implementation, this study aims to support policy-makers, urban planners, and logistics operators. It provides actionable recommendations for the development of integrated strategies that promote sustainable, inclusive, and efficient urban logistics systems. Ultimately, these efforts contribute to broader goals such as urban decarbonisation, improved quality of life, and enhanced operational efficiency.

The paper is structured as follows. After the description of the methodology used to develop the systematic literature review, the findings are presented, highlighting the key impacts, challenges, and opportunities associated with the transition to eco-freight vehicles. Finally, this paper concludes with recommendations for future research and practical strategies, underlining the importance of using an integrated approach.

2. Methodology

Researchers can use bibliometric analysis, a quantitative method for examining and summarising published studies, to evaluate academic research on a specific topic (Ding and Yang, 2022; Hu et al., 2019; Ji et al., 2023; Kiba-Janiak et al., 2021). This technique uses secondary data from digital databases, providing an objective, data-driven perspective. Bibliometric analysis establishes a systematic, transparent, and replicable process for evaluating literature, enhancing the reliability of the review.

The methodology used in this study consists of the following steps (Figure 1):

(i) *Initialisation*: creation of a scientific dataset based on defined inclusion and exclusion criteria, which guarantee the relevance and quality of the selected studies,

(ii) *Identification*: selection of relevant keywords and use of Boolean operators to optimise search results in databases,

(iii) *Screening and eligibility*: selection of relevant articles with the elimination of duplicates or irrelevant studies, and

(iv) *Data analysis*; detailed review of the articles included in the dataset, including reviews of content and trends.

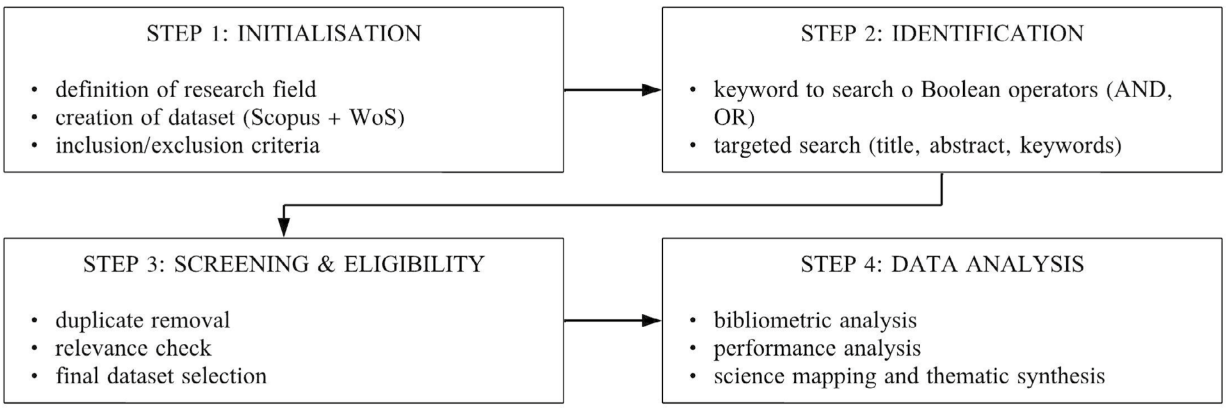

Figure 1. Methodology framework.

Although the methodology adopted ensures a rigorous and replicable process, it is important to acknowledge certain limitations inherent in systematic reviews and bibliometric analyses. The use of predefined search strings and the reliance on indexed databases such as Scopus and the Web of Science may lead to the exclusion of relevant contributions, especially those that do not contain specific keyword combinations in titles or abstracts. For example, some studies related to the utilisation of electric vehicles in city logistics, the development of charging infrastructure, or their environmental impact may not be indexed or may lack the specific terms used in the search strategy. To overcome this limitation, the authors complemented the bibliometric approach with targeted inclusion of relevant studies identified through expert knowledge and backward snowballing (i.e., citation tracking), integrating traditional review methods into the analysis to ensure a more comprehensive coverage of the literature.

3. Results

Following the methodology outlined, the literature review has been developed systematically, progressing through the predefined stages as detailed in the sections below. The first step (*initialisation*) involved defining the field of knowledge to be explored. Following this, a scientific dataset was compiled to serve the objectives of this study. Subsequently, the relevant keywords related to the study topic, namely the impact assessment of electric vehicles for urban freight transport, were selected. The research used datasets from Scopus and the Web of Science (WoS for a comprehensive review, leveraging the WoS for historical coverage and Scopus for a broader range of academic journals. The search was performed according to various criteria for inclusion or exclusion, such as title and abstract. Time interval, type of document (journals, conference proceedings, book chapters) and language (English) have been further used for refining the search.

Once the relevant keywords were determined, the next stage was the identification of relevant works to review (*identification*). Data collection was refined by employing Boolean operators (OR, AND), as described in Table 1, to strategically combine the terms and enhance the search results across the selected datasets (Scopus and the WoS). The search process focused on identifying keywords within the title, abstract, and keyword fields, to ensure a comprehensive and targeted dataset.

Table 1. Summary of the methodology application,

Search phrase	**Documents**	**To review**
("urban freight" OR "city logistics" OR "urban goods" OR "last mile deliver*" OR "urban logistic*" OR "freight distribution") AND ("eco vehicle*" OR "electric vehicle*" OR "hydrogen vehicle*" OR "eco-friendly vehicle*" OR "green vehicle*" OR "green logistic*" OR "ecofriendly vehicle" OR "eco friendly vehicle" OR "pollutant emission*" OR "sustainable logistic*" OR "sustainable mobility") AND ("assessment" OR "evaluation" OR "CBA" OR "cost-benefit analysis" OR "cost benefit analysis" OR "financial appraisal" OR "effect*")	200[*] 263[**] 44[***] **419**[****] 155[*****]	**264**

[*] = WoS; [**] = Scopus; [***] = excluded; [****] = total; [*****] = duplicates

Subsequently the *screening, eligibility and inclusion* stages were implemented. Preliminary selection was made, considering only studies in English published after the year 2000. Subsequently, irrelevant work was identified and excluded through an analysis of abstracts. A total of 264 papers were identified and selected as worthy of review. The final phase focuses on reviewing the studies included in the analysis to perform the bibliometric analysis, which includes performance analysis and science mapping. Performance analysis often uses citation counts to gauge the relative importance and influence of publications, authors, journals, institutions, and countries, and it may also involve calculating the average citations per work. Science mapping typically involves co-citation analysis and evolution analysis. The reviewed works belong to various types of publications, i.e., journals, conference papers and book chapters. As emerged, no relevant work prior to 2010 was found through the searches carried out, confirming that research interest in eco-friendly vehicles is quite recent.

To correctly interpret the data generated by the bibliometric analysis, the following statistical parameters have been used:

(i) the centrality of the interactions (*w*), according to graph theory, it is an indicator used to assess the importance of nodes within a network; it measures how often a node acts as an intermediary between two other nodes in the network,

(ii) burst strength (*BS*) is an indicator that quantifies the citation burst, which refers to the time window during which an author or paper suddenly experiences a sharp increase in citations, and

(iii) mean silhouette (*S*) and modularity (*Q*) were used to measure internal cohesion and separation between clusters; a high modularity value indicates that the network is well divided into distinct clusters, while a high silhouette value suggests that nodes within a cluster are strongly correlated with each other.

Data analysis allowed *11* primary thematic groups to be identified. The primary thematic clusters, shown in Table 2, are those with high silhouette scores and internal coherence (Olawumi and Chan, 2018) because they represent groups of articles with well-defined themes. Table 2 reports the main groups identified along with their silhouette values, the number of studies and the average year.

Table 2. Summary of the 11 largest clusters.

ClusterID	Size	Silhouette	Label (LLR)	Core Year
1	35	0.945	Urban freight impact	2013
2	11	0.973	Normative legislative measures	2014
3	25	0.918	Barriers and risks of implementing sustainable solutions	2017
4	38	0.921	Urban freight supply innovation	2016
5	28	0.796	Long / short haulage logistics	2020
6	33	0.940	On-demand logistics	2019
7	16	0.980	Routing problem	2020
8	33	0.811	Routing electric vehicle	2016
9	28	0.935	Electric vehicle charging issues	2014
10	10	0.965	Routing and charging location	2011
11	42	0.913	Electric robot deliveries	2020

4. Impact assessment

Based on this analysis, it is, therefore, possible to focus on the need to investigate current assessment frameworks for the use of electric vehicles in urban logistics and to evaluate potential revisions to identify new challenges. After identifying the main clusters, the analysis focused on the clusters with the highest silhouette index, and within each, the studies with the highest number of citations have been reviewed. Subsequently, papers with the highest centrality index (Hu et al., 2019; Vignery and Laurier, 2020) have been examined, as these papers served as key references for this study and are connected to other works that could further deepen the research. The burst (Kleinberg, 2003) index was also crucial, as it guided the analysis to periods when the topic gained sudden relevance, leading the research to identify the challenges, techniques, impacts and perspectives the use of eco-friendly vehicle for urban logistics. The use of eco-friendly solutions for urban logistics, particularly for last-mile delivery, can have several positive and critical impacts. Here are some of the main ones:

(i) environmental impacts,

(ii) economic impacts,

(iii) social impacts,

(iv) operational and infrastructural impacts, and

(v) regulatory and compliance impacts.

4.1. Environmental impacts

Current environmental impact assessment of eco-friendly vehicles in urban logistics, particularly for last-mile delivery services, has so far shown encouraging results. The adoption of electric vehicles, cargo bikes and other lowemission solutions has led to a significant reduction in CO_2 emissions and an improvement in air quality in urban areas (Browne et al., 2011; Comi and Hriekova, 2024; Napoli, Polimeni et al., 2021). Another consequence is a decrease in noise pollution. These benefits are crucial for the sustainability of modern cities, where the growing demand for fast home deliveries has increased traffic and pollution. However, with the continuous evolution of technology and the increasing complexity of urban logistics, it is necessary to update current environmental impact assessments to address new challenges (Alarcón et al., 2023) guided by emerging technologies such as drones and autonomous vehicles, which are changing the landscape of urban logistics and require the integration of new parameters into environmental assessment models (Arntz et al., 2023; Garg et al., 2023). Many governments, including Germany (Taefi et al., 2016), China (Lu, T. et al., 2022), Norway (Yang, A. et al., 2023), are encouraging the adoption of eco-friendly vehicles in cities by offering public subsidies and other incentives. In the future, a more comprehensive approach will be needed, taking into account the entire life cycle of eco-friendly vehicles (Russo and Comi, 2024a). This includes not just the emissions produced during vehicle use, but also the environmental impact from the production and storage of energy, such as battery manufacturing, electricity for charging, and the recycling or disposal of vehicles and their parts.

4.2. Economic impacts

One of the main economic advantages of using electric vehicles for urban logistics lies in the reduction of operational costs; numerous studies support this, including one conducted in the city of Oporto (Alvarez-Palau et al., 2021; Melo et al., 2014; Melo and Baptista, 2017). Electric vehicles, for example, have significantly lower fuel costs compared to internal combustion engine vehicles, thanks to higher energy efficiency and lower electricity prices compared to fossil fuels (De Cauwer et al., 2015). However, it is relevant to take into account the entire production energy cycle (Russo and Comi, 2024a). However, a prerequisite for the introduction of e-mobility is a well-developed and well-managed charging infrastructure for electric vehicles (Wątróbski et al., 2017). Tax incentives and government subsidies have played a crucial role in making the adoption of these technologies more accessible. Many governments offer tax breaks, purchase discounts, and other forms of financial support for the acquisition of eco-friendly vehicles and the installation of related charging infrastructure for electric vehicles.

However, while the long-term economic benefits are clear, emerging economic challenges require a review of current evaluations. Electric vehicles, although having lower operating costs, have a higher initial cost compared to traditional vehicles (Bertolini et al., 2024). This cost is amplified by the need to invest in charging infrastructure, which must be widely distributed to support efficient last-mile delivery operations. However, the cost could be reduced over time with proper planning and an improvement in operational efficiency (Narayanan and Antoniou, 2022). The limited range and load capacity of eco-friendly vehicles may increase operational costs, requiring more vehicles or frequent recharging stops. Adapting infrastructure for new technologies like drones and autonomous vehicles adds further costs. Additionally, integrating renewable energy and developing a multilevel delivery network will be crucial, involving costs for load transfers, upgrading energy grids, and integrating green energy technologies (Russo and Comi, 2024b).

4.3. Social impacts

Reducing air and noise pollution improves public health by lowering respiratory and cardiovascular diseases, while the visibility of sustainable technologies promotes environmental awareness and eco-friendly behaviour (Omahne et al., 2021). However, new challenges require social assessments to evolve. The adoption of eco-friendly vehicles and advanced technologies like drones and autonomous vehicles may change work habits, reducing demand for traditional labour and raising concerns about unemployment and the need for worker retraining. Accessibility and equity are crucial, as sustainable mobility must serve all urban areas, including underserved neighbourhoods (Wang, Y et al., 2023). Concentrating charging infrastructure and eco-friendly vehicles in privileged areas risks creating disparities and excluding disadvantaged communities. While these technologies can enhance urban spaces, careful management is needed to prevent negative effects such as gentrification or increased living costs in affected areas.

4.4. Operational and infrastructural impacts

Currently, the adoption of electric vehicles and other sustainable technologies has shown improvements in terms of operational efficiency and savings in fuel and maintenance costs. However, to address emerging challenges and effectively support the implementation of these vehicles, a deeper understanding of various operational and infrastructure aspects is needed (İmre et al., 2021). Eco-friendly vehicles and cargo bikes can improve operational efficiency due to reduced fuel and maintenance costs, but their load capacity and range can limit their application, especially for large-volume deliveries or significant distances. In fact, EVs are very efficient for small urban contexts and, therefore, short distances to cover, as demonstrated by a research study within the EUFAL international project conducted in the Polish town of Szczecin (Iwan et al., 2021).

In addition, extra costs could occur for transferring goods from one vehicle to another (Narayanan and Antoniou, 2022). Companies must also carefully manage route planning and charging times to optimise the use of these vehicles. In fact, some empirical studies show that the length of the routes in city centres could even increase due to the often more restrictive load limits of eco-friendly vehicles and the costs of transferring could be significantly optimised through the use of emerging technologies (Russo and Comi, 2024a). The transition to eco-friendly vehicles requires companies to adapt their logistics processes, including restructuring warehouses and adopting data analysis tools and route optimisation software to manage fleets effectively, considering range and charging limitations. These changes require investment, training and strategic infrastructure. Drones and autonomous vehicles pose additional challenges, requiring dedicated spaces and road adaptations, requiring targeted urban planning.

4.5. Regulatory and compliance impacts

Currently, environmental regulations and sustainability policies drive a reduction in emissions and greater energy efficiency, incentivising the adoption of electric vehicles and other green technologies. However, to address the new challenges associated with the increasing use of this type of vehicle, a review and adjustment of existing regulations will be necessary (Alanazi, 2023). In addition, the importance of integrated policy frameworks that not only incentivize EV adoption, but also regulate infrastructure expansion and battery management has emerged. Comprehensive regulations are needed to support long-term sustainability and carbon reduction goals in the transportation sector (Maltese et al., 2021).

4.6. Discussion

In summary, while eco-friendly vehicles show benefits for last-mile deliveries, emerging challenges require updated evaluation methodologies to support sustainable urban logistics growth (Aifandopoulou and Xenou, 2019; Comi et al., 2020). Economic assessments should adopt a strategic, integrated approach, considering direct and indirect costs, long-term benefits, and the entire logistics ecosystem, including infrastructure and technology integration. Models should be adaptable to evolving technologies (Angreani et al., 2020; Facchini et al., 2019) and policies to ensure long-term sustainability and competitiveness. Further analysis is needed to assess the maturity (Kijewska et al., 2021) and transferability (Kijewska and Iwan, 2019) of results, as current research focuses on sustainability performance but lacks comprehensive solutions for autonomous logistics systems and their application in different urban contexts (Nathanail et al., 2021).

5. Conclusions

The study offers a comprehensive assessment of the impact of eco-friendly (green) vehicles in urban logistics, emphasising the need for an integrated approach to address transition challenges. It identifies innovative solutions to improve operational efficiency, such as route optimisation and charging infrastructure expansion, while highlighting the need for regulatory updates. The study also considers the impact on urban infrastructure and potential social inequalities arising from limited access to these technologies.

These actions would provide measurable reference points to evaluate progress and support evidence-based policy-making. From a practical perspective, the findings of this study suggest three main key-directions of action: 1) in each city according to its specificity, define realistic and measurable emission-reduction targets for urban freight transport, in line with the ones suggested by Agenda 2030; (2) implement demonstrative projects in selected urban areas to test integrated delivery schemes combining electric vans, cargo bikes, and micro-hubs, while monitoring operational performance and user acceptance, aiming to identify pros and cons for their large-scale implementation; (3) establish a national/regional monitoring and reporting framework coordinated by local authorities to collect standardised data on vehicle energy consumption, delivery cost, and service reliability; this would enable evidence-based policy-making and continuous improvement of sustainable urban logistics strategies, thus supporting the transferability of policy/measure outcomes. These recommendations could provide actionable and quantifiable steps for policy-makers, transport and logistics operators to translate sustainability goals into measurable outcomes, accelerating the transition to eco-friendly urban freight systems.

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