

Carbon Emissions in Informatics-Enabled Last-Mile Logistics Service Systems: A Bibliometric Analysis (2008–2024)

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Abstract. To gain a comprehensive understanding of the research landscape and development trends in carbon emissions within informatics-enabled last-mile logistics service systems, this study conducted a bibliometric and visual analysis of relevant publications from 2008 to 2024 based on the Web of Science (WoS) Core Collection. The study frames last-mile carbon emissions within an informatics-driven logistics service system perspective. Using VOSviewer and CiteSpace, it maps research hotspots, theme evolution, and the knowledge base in this field. The findings indicate that: (1) a stable core group of authors has yet to emerge, suggesting that the field is still in a phase of rapid growth with significant potential; (2) research outputs are primarily published in journals related to sustainability, transportation, and environmental science, with open-access platforms such as *Sustainability* playing a key role in knowledge dissemination; (3) the research scope continues to expand, with future directions likely to focus on informatics-driven delivery strategies, green technology applications, and individual sustainable behaviours; and (4) the co-citation network does not yet exhibit a highly centralised structure, indicating that the knowledge base is still forming and reflecting characteristics of interdisciplinarity, problem-driven research, and integration of technology and service.

Keywords: E-commerce, Last mile, Carbon Emission, Bibliometrics, Informatics, Visual Analysis

1. Introduction

The rapid expansion of e-commerce has significantly transformed global trade, consumer behaviour, and logistics systems. E-commerce platforms connect supply and demand through information technology, offering consumers efficient and convenient access to goods and services. In 2024, global e-commerce transactions exceeded USD 6 trillion and are projected to reach approximately USD 8.09 trillion by 2028, with an average annual growth rate of 7.6%. This growth has expanded the logistics industry and driven the adoption of data-driven operations, platform coordination, and service system optimisation. These trends are particularly evident in last-mile delivery, the critical stage linking distribution centres to end consumers (Lim et al., 2018). Figure 1 presents projected market growth for last-mile e-commerce delivery.

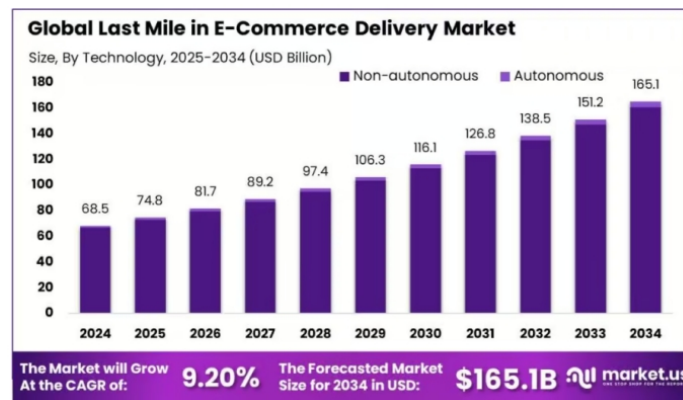


Fig. 1: Global Last Mile in E-Commerce Delivery Market

Source: Global Last Mile in E-Commerce Delivery Market Size, Share, Statistics Analysis Report. <https://market.us/report/last-mile-in-e-commerce-delivery-market/>

While generating substantial economic value, e-commerce also imposes significant environmental pressures, particularly carbon emissions (Yu et al., 2024). Higher-order volumes increase demand for packaging, warehousing, transport, and reverse logistics, resulting in higher energy consumption and greenhouse gas emissions (Pålsson et al., 2017). Dispersed delivery routes, low vehicle utilisation, and high delivery frequency make last-mile delivery the most carbon-intensive segment of the e-commerce logistics chain (Zhang et al., 2024).

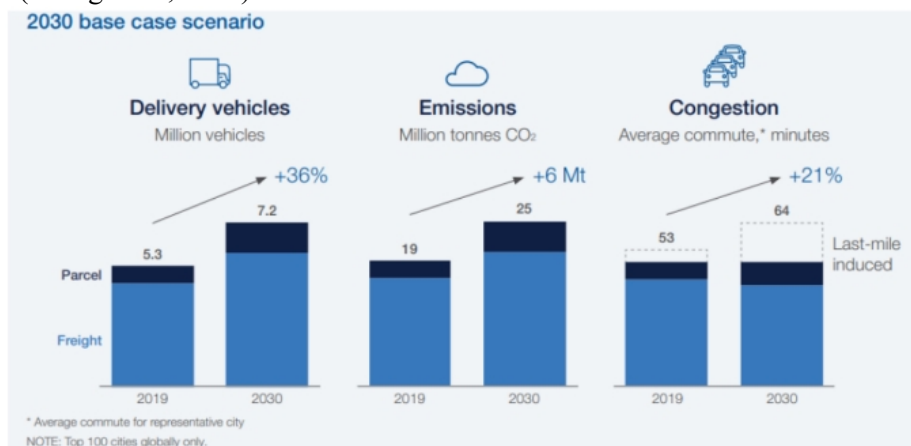


Fig. 2: The Impact of Last-Mile Delivery Development on Urban Traffic and Carbon Emissions

Source: How Last-Mile Delivery Companies Can Reduce Their Carbon Footprint, <https://blog.route4me.com/how-last-mile-delivery-companies-can-reduce-their-carbon-footprint/>

Last-mile delivery should not be viewed solely as a transport challenge. It functions as an informatics-enabled logistics service system (Comi & Hriekova, 2024), relying on route optimisation algorithms, real-time tracking, IoT platforms, and scheduling systems. Decisions regarding delivery time windows, same-day or instant delivery, return policies, delivery frequency, and customer interactions directly affect vehicle utilisation, route efficiency, and carbon emissions per order. Figure 2 illustrates the potential impact of last-mile delivery on urban traffic and carbon emissions under a 2030 baseline scenario.

Carbon emissions are shaped not only by transport activities but also by service design, information flows, and decision-support systems. Data-driven demand forecasting, dynamic route planning, intelligent scheduling, and real-time IoT information sharing enhance resource allocation, reduce empty travel, and improve delivery coordination. Consequently, carbon emissions emerge from the combined effects of technology, service design, and informatics capabilities.

From the perspective of urban sustainability and climate governance, promoting low-carbon transformation of last-mile logistics systems is a critical priority (Paddeu, 2025). Last-mile delivery is the densest carbon-emitting node in logistics networks, with frequent deliveries, high order volumes, and rising service expectations. Effective carbon reduction depends not only on vehicle electrification and infrastructure upgrades but also on the structural design of logistics service systems, coordination mechanisms, and digital support capabilities (Olsson, 2023). Measures such as smart lockers, community pick-up points, collaborative delivery platforms, and optimised delivery time windows enhance service quality while significantly reducing carbon intensity.

Existing research has examined last-mile carbon emissions from perspectives including route optimisation (Tiwari & Sharma, 2023), the use of new-energy vehicles, urban logistics policy interventions (Castillo & Álvarez, 2023), and technological innovations affecting emission performance (Demir, 2022). These studies provide valuable insights, yet the literature remains dispersed across logistics, transport, sustainability, and information systems. Few studies systematically integrate findings to explain how informatics-enabled logistics service models influence carbon emissions or how service design interacts with urban logistics systems. This highlights that low-carbon last-mile delivery remains an emerging and interdisciplinary research area. Bibliometric analysis can integrate the knowledge structure, reveal research trends, and support theoretical development and agenda setting.

Using literature from the Web of Science Core Collection from 2008 to 2024, this study conducts a bibliometric analysis with VOSviewer and CiteSpace. Descriptive statistics identify core authors, leading countries and institutions, key journals, and representative publications to reveal the knowledge base and research capacity. Keyword co-occurrence and temporal evolution analyses explore thematic structures and development trends. By framing last-mile e-commerce delivery as an informatics-enabled logistics service system, this study provides a systematic review of research on environmental sustainability. It offers guidance on cross-disciplinary research, the design of low-carbon logistics service systems, digital investment, and urban policymaking.

2. Literature Review

2.1. Last-Mile Delivery and Carbon Emissions

The rapid growth of e-commerce has made last-mile delivery a major contributor to urban greenhouse gas (GHG) emissions. Studies indicate that fragmented delivery, traffic congestion, and high delivery failure rates make last-mile logistics one of the most energy-intensive and environmentally impactful stages of the supply chain (Ha et al., 2023). Empirical evidence from different countries shows that the expansion of e-commerce-driven last-mile delivery significantly increases urban carbon emissions (Arunan & Crawford, 2021). At the same time, some research suggests that under certain conditions, the per-product carbon footprint of e-commerce delivery may be lower than that of traditional retail, highlighting the context-dependent nature of its environmental

impact (Béziat & François, 2024).

Research on last-mile carbon emissions in e-commerce is extensive but dispersed across disciplines. Existing studies examine vehicle technology, operational optimisation, policy measures, and consumer behaviour (Jaller et al., 2023; Caggiani et al., 2021). While these studies provide valuable insights into specific emission reduction pathways, most focus on particular technologies, operational scenarios, or behavioural assumptions. Few studies integrate findings systematically across the field, limiting the development of a comprehensive understanding of last-mile carbon emissions.

2.2. Limitations of Traditional Reviews and the Need for Bibliometric Analysis

Traditional narrative reviews have helped summarize emission reduction measures and technological innovations, including electrification, route optimisation, and alternative delivery modes (Llorca & Moeckel, 2021). In a field that is rapidly growing and highly interdisciplinary, these reviews have notable limitations. They provide limited insight into the overall knowledge structure, the evolution of themes, and shifts in research paradigms. They are also unable to systematically identify dominant research clusters, emerging topics, or patterns of development over time.

Bibliometric analysis offers a systematic and objective approach to address these limitations. It integrates diverse research outputs and can reveal knowledge structures and evolutionary trajectories that are difficult to capture through traditional narrative reviews (Brancaleoni et al., 2025). Unlike reviews that focus on specific technologies or delivery modes, bibliometric methods allow a broader understanding of how research on last-mile carbon emissions develops across disciplines, differentiates into subfields, and gradually forms interconnected research networks.

This study conducts a systematic bibliometric analysis of the literature on last-mile carbon emissions in e-commerce published from 2008 to 2024. It aims to map the knowledge structure, identify key research streams, and highlight emerging directions, providing a structured reference for future research on low-carbon urban logistics and informatics-enabled logistics service systems.

2.3. Logistics Informatics as a Core Mechanism in Low-Carbon Last-Mile Delivery

From an evolutionary perspective, logistics informatics has shifted from a supporting tool to a central mechanism in last-mile delivery. In the early stage, information technologies were applied to basic operational tasks such as order tracking, vehicle positioning, and static route planning, with the main focus on improving delivery efficiency and operational control.

As urban delivery systems became more complex and pressure to reduce carbon grew, informatics began to support real-time coordination and system optimisation. Route adjustments, order consolidation, and vehicle scheduling increasingly relied on data-driven approaches rather than experience-based decisions, reducing empty travel and improving resource utilisation. The emergence of platform-based delivery and crowdsourced logistics further highlighted the role of informatics in coordinating multiple agents, matching supply and demand, and monitoring energy consumption.

In low-carbon last-mile logistics, informatics is no longer a mere operational tool. It has become a critical mechanism linking logistics decisions, service system design, and environmental performance. Conceptualising last-mile delivery as an informatics-enabled logistics service system helps to identify the common informatics logic underlying diverse service strategies. It also offers a valuable theoretical perspective on carbon-reduction pathways in last-mile operations.

Building on this informatics-oriented view, the subsequent bibliometric analysis interprets research findings in relation to different logistics service strategies and their underlying informatics frameworks, providing insights into how information technologies shape low-carbon delivery practices.

3. Research Methods and Data Sources

3.1. Research Methods

Bibliometrics is a quantitative research method used to describe and analyse the dynamics and development of disciplines or research fields based on publication, citation, and textual data (A van Raan, 2019). In addition to descriptive statistics, bibliometric analysis involves network analyses of keywords, texts, citations, authors, institutions, and their interrelationships. Through clustering analyses of authors, journals, and countries, as well as temporal evolution analysis of keywords, researchers can trace the development of research questions, identify trends in the literature, and map citation networks. In this study, we employ two visualisation tools—VOSviewer and CiteSpace—to conduct a bibliometric analysis of research on carbon emission reduction in the last-mile delivery segment of e-commerce.

3.2. Data Sources

The Web of Science (WoS) database, maintained by Clarivate, is one of the most reliable sources for scientific literature and bibliometric data (Adeleke et al., 2025). Compared with PubMed, Scopus, and Google Scholar, WoS provides more accurate and consistent data and offers a standard framework for accessing research across disciplines (Asha'ari et al., 2024).

For this study, the Web of Science Core Collection (WoSCC) was selected as the sole data source because it aligns with the research objectives and bibliometric methodology. WoSCC offers clear advantages in journal selection, citation consistency, and reproducibility. Other databases were not used to maintain dataset standardisation and ensure robust results.

To reduce potential bias from a single field, publications from the Social Sciences Citation Index (SSCI), Science Citation Index Expanded (SCI-Expanded), and Emerging Sources Citation Index (ESCI) were included. These indices cover management, environmental science, and related interdisciplinary areas. This selection ensures both the reliability and completeness of the dataset while covering research across social and natural sciences.

To construct the dataset, highly cited literature on last-mile carbon emissions in e-commerce delivery was reviewed to identify relevant keywords. The topic search (TS) used the title, abstract, and author keywords as follows:

TS = (("carbon*" OR "emission*" OR "greenhouse gas*" OR "CO2") AND ("e-commerce" OR "online shopping" OR "electronic commerce" OR "online retail*" OR "parcel*" OR "delivery" OR "courier") AND ("last mile" OR "urban logistics" OR "city logistics" OR "urban freight" OR "urban delivery" OR "home delivery" OR "last mile distribution" OR "final delivery"))).

A literature search was conducted on 8 July 2025 for publications between 1 January 2008 and 31 December 2024. Publications from 2008 to 2017 were limited in number, reflecting the early development and exploratory stage of research on last-mile carbon emissions and providing a foundation for subsequent growth. All searches were performed on the same day to control for daily database updates. Only English-language publications were included, and only peer-reviewed journal articles were considered. Book chapters, conference papers, early access articles, and data papers were excluded.

A total of 484 records were identified in the initial search. Next, title and abstract screening were conducted. During this step, 262 studies were excluded because they were not closely related to the research topic. These excluded studies included those not focused on last-mile delivery, pure engineering or energy studies, consumer or marketing-oriented e-commerce research, passenger transport studies, and studies without relevance to carbon emissions. Finally, 262 high-quality and highly relevant articles were retained as the research sample. The data were then exported in full-record format, including cited references, and saved as plain text files for further bibliometric analysis. Figure 3 presents the detailed process of literature search and screening.

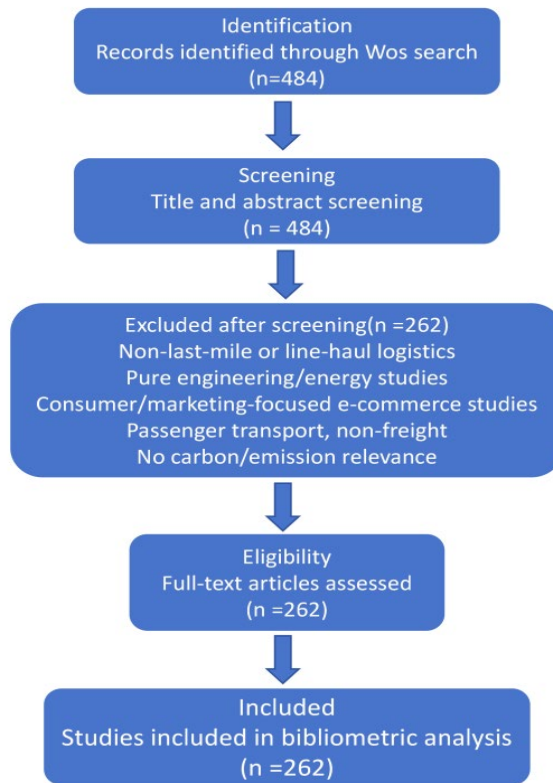


Fig. 3. Flowchart of Literature Search and Screening Process

To ensure a clear research framework, Figure 4 illustrates the main workflow of the bibliometric analysis conducted in this study.

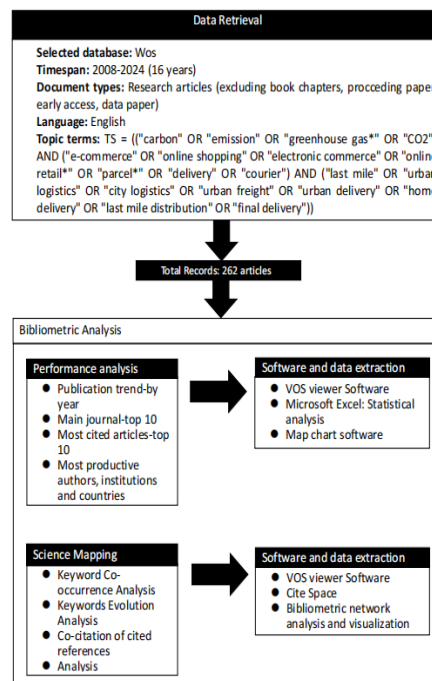


Fig. 4: Research procedure.

Figure 5 illustrates the temporal distribution of publications related to carbon emissions in the last mile of e-commerce logistics. Overall, the number of publications in this field has been steadily increasing, clearly reflecting growing academic interest in this research topic. The period from 2008 to

2017 was the nascent stage. Notably, since 2017, the number of publications has been growing rapidly, with the annual count exceeding 40 in 2022, 2023, and 2024. This trend indicates that the topic has become a research hotspot in carbon reduction, gaining widespread recognition for both its academic value and practical significance.

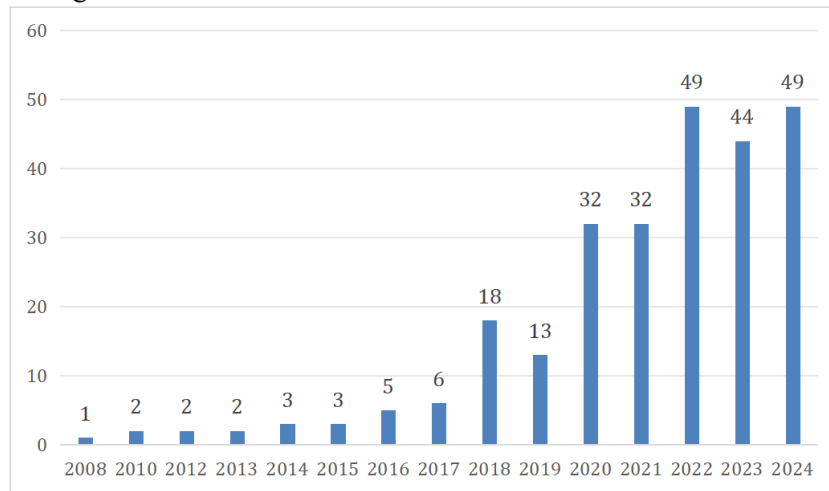


Fig. 5: Distribution of publications from 2008 to 2024

A preliminary analysis of the literature in VOSviewer yielded a dataset comprising 262 articles, authored by 810 researchers affiliated with 372 institutions across 45 countries, published in 84 journals, and containing 10,534 citations from 5,085 unique journals.

3.3. Bibliometric Analysis Procedure and Parameter Settings

To ensure reproducibility, this study applied consistent parameter settings in both VOSviewer and CiteSpace. VOSviewer was used to analyze keyword co-occurrence and co-citation. The minimum occurrence threshold for keywords was set to 5. For co-citation analysis, the minimum citation threshold was set to 30 for journals and 10 for references.

CiteSpace was used for keyword evolution and co-citation clustering. The time slicing was set from 2008 to 2024, with one year per slice. Node selection was based on the g -index with $k = 25$. To simplify the networks and highlight key links, Pathfinder pruning was applied. Pruning sliced networks and pruning the merged network were also enabled. Cluster labels were generated using the log-likelihood ratio (LLR) algorithm.

4. Descriptive Statistics of Findings

This section presents a bibliometric analysis of research on carbon emissions in e-commerce last-mile delivery, focusing on academic outputs at the levels of journals, authors, and countries. The analysis examined publication counts, citation numbers, and distribution patterns, identifying core journals, leading scholars, and highly productive countries. The findings reveal the research structure, development trends, and scholarly impact of this emerging field. They provide a foundation for understanding the key knowledge sources and the global research landscape in sustainable urban logistics and low-carbon last-mile delivery.

4.1. Bibliometric Analysis of Journals

According to the bibliometric analysis, the most relevant publications appear in journals on sustainable development, transportation, and environmental sciences. This distribution pattern clearly reflects the field's central focus on green transportation and environmental sustainability. The following is a list of the top 10 journals by publication volume in this research area:

Table 1. Top 10 journals in the carbon emission field of the last mile in e-commerce

Rank	Source	Publications	Citations	Average Citation/Publication
1	sustainability	39	638	16.4
2	Transportation Research Part D: Transport and Environment	21	1130	53.8
3	Transportation Research Record	15	246	16.4
4	energies	11	161	14.6
5	environmental science & technology	11	1033	93.9
6	journal of cleaner production	8	319	39.9
7	research in the transportation business and management	8	141	17.6
8	research in transportation economics	7	179	25.6
9	European Transport Research Review	6	324	54.0
10	international journal of logistics-research and applications	6	228	38.0
11	Total	132	4399	37.0

According to the table, three journals have published more than 15 articles in this research domain. Sustainability ranks first with 39 publications, followed by Transportation Research Part and Transport and Environment, each with 21, and Transportation Research Record with 15. Notably, Sustainability is a fully open-access journal, suggesting that open-access publishing has significantly contributed to the dissemination and development of research in this field in recent years.

In terms of total citations, Environmental Science & Technology (1,033) and Transportation Research Part D (1,130) stand out, indicating their strong academic influence within the field. Further analysis of average citations per article shows that Environmental Science & Technology averages 93.9 citations per publication, reflecting its strong academic authority. As a leading journal in environmental science, it primarily publishes articles on the optimisation of transportation systems and the application of information technology to reduce carbon emissions.

Bradford's Law is a key tool for analysing the distribution of journal literature across disciplines (Bradford, 1976). It reveals that within a seemingly disordered set of scientific publications, literature in a specific field tends to exhibit a highly skewed distribution among journals. Journals publishing on a given topic are not evenly distributed; they show a clear core-periphery structure, in which a small number of core journals account for a large proportion of the literature. According to the law, if journals are ranked in descending order by the number of relevant articles they publish and divided into groups with equal numbers of articles, the number of journals in each group follows a geometric progression, typically in the ratio of 1: a : a²: This illustrates both the concentration of scholarly output in a few key journals and the diminishing returns of searching beyond the core set.

Table 2. Journal Partition

Zone	Publications/Journal	Number of Journals	Number of Publications
First Zone	≥11	5	97

Zone	Publications/Journal	Number of Journals	Number of Publications
Second Zone	3-8	17	82
Third Zone	1-2	60	83
Total		82	262

In the field of last-mile carbon-emission reduction research, the distribution of journals by publication volume is shown in Table 2. When the journals are divided into three zones such that each zone contains approximately the same number of articles, the number of journals in each zone follows a ratio of approximately 1:3:9 (i.e., 1:a:a²). This pattern accords with Bradford's Law and reveals a clear core-periphery structure within the literature. Beyond the numerical distribution, this structure has theoretical implications. A small group of core journals accounts for most publications, indicating that the field—situated at the intersection of logistics, information systems, and sustainability—is still emerging and inherently interdisciplinary. In contrast, the large number of peripheral journals suggests that the topic remains exploratory. A stable and widely recognised central research framework has yet to take shape.

4.2. Bibliometric Analysis of Authors

Analysing the contributing authors helps identify leading scholars and core research groups in this field. According to Price's Law, approximately half of the publications in a specific research area are authored by a group of prolific researchers, whose size is approximately the square root of the total number of authors in that field (Price, 1963).

$$\sum_{m+1}^I n(X) = \sqrt{N} \quad (1)$$

Let formula (1) represent Price's Law, $n(x)$ denotes the number of authors who have published x papers, $I=n_{\max}$ is the highest number of publications by a single author (in this study, $n_{\max}=5$), N is the total number of authors, m is the minimum number of papers required to be considered a core author, The threshold m can be estimated using the formula:

$$m = 0.749 \times \sqrt{n_{\max}} \approx 1.67 \quad (2)$$

Thus, authors with at least two publications are preliminarily identified as core contributors in this research domain. However, when applied to Price's Law, the empirical data indicate that the distribution does not fully conform to the expected pattern. The field of low-carbon last-mile delivery has not yet developed a stable core group of authors. This reflects its relatively recent emergence, its interdisciplinary nature, and its problem-driven orientation. The academic ecosystem remains in its early stages of development, and scholarly influence has not yet become highly concentrated. In addition, this study is based solely on the Web of Science Core Collection. The sample size is therefore limited, which may affect the representativeness and generalisability of the observed author distribution.

Overall, the dispersion of authors and journals not only reveals the current pattern of research output but also highlights the early-stage, exploratory, and problem-oriented character of research on low-carbon last-mile delivery at the intersection of logistics, information science, and sustainability.

Next, Table 3 shows that among the most prolific authors in the field, Gatta, V. and Marcucci, E. stand out with five co-authored publications between 2008 and 2024, totaling 398 citations and averaging 79.6 citations per paper. Gatta is affiliated with the University of Roma Tre, while Marcucci is based at the Department of Logistics, Molde University College in Norway.

Table 3. The most important authors in the carbon emission field of the last mile in e-commerce

Rank	Author	Documents	Citations	Average Citation/Publication
1	Gatta, V.	5	398	79.6
2	Marcucci, E.	5	398	79.6
3	Jaller, M.	4	202	50.5
4	Winkenbach, M.	4	180	45
5	Liu, D.	4	101	25.25
6	Keoleian, G. A.	4	51	12.75
7	Hinde, C.	4	50	12.5
8	Schnieder, M.	4	50	12.5
9	West, A.	4	50	12.5
10	Goodchild, A.	4	42	10.5
11	Total	37	1124	

Their research primarily focuses on the sustainability of urban logistics and the environmental impacts of e-grocery delivery (Aziz et al., 2022; Gatta et al., 2018; Gatta et al., 2019; Marcucci et al., 2024; Simoni et al., 2020; Suh et al., 2012). By integrating themes such as urban freight transport, crowdsourced logistics, environmental impact assessment, and green delivery strategies, their studies contribute to the broader discourse on the sustainable development of the logistics industry.

4.3. Bibliometric Analysis of Countries

To identify which countries have made the most prominent contributions to research on last-mile carbon emission reduction, this study analysed publication volumes across 45 countries. Specifically, Figure 6 presents a statistical breakdown of the top 10 countries by publication count.

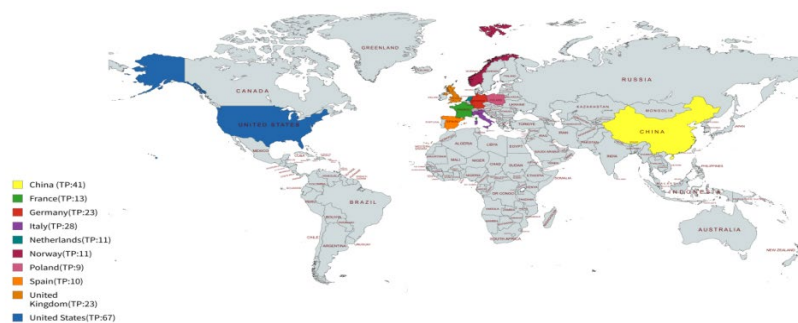


Fig.6: The number of publications for each geographic region in the world map. The map was generated using the web link: <https://mapchart.net/world.html>.

From Figure 6, the top ten countries by publication count are the United States, China, Italy, the United Kingdom, Germany, France, the Netherlands, Norway, Spain, and Poland.

Further analysis of the data in Table 4 clearly illustrates the academic output and influence of different countries in the field. The United States ranks first with 67 publications and an average citation count of 54.2. China follows with 41 publications, though its average citation rate is relatively lower at 27.8. Notably, Germany, despite having only 23 publications, holds the highest average citation rate of 69.3. This is largely due to the high citation impact of individual papers, particularly Schneider M.'s

paper, which has been cited 819 times, significantly boosting Germany's overall average.

Table 4. The most important countries in the carbon emission field of the last mile in e-commerce

Rank	country	documents	citations	Average Citation/Publication
1	United States	67	3632	54
2	China	41	1138	28
3	Italy	28	901	32
4	United Kingdom	23	671	29
5	Germany	23	1595	69
6	France	13	163	13
7	Netherlands	11	855	78
8	Norway	11	454	41
9	Spain	10	136	14
10	Poland	9	158	18
11	Total	236	9703	

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5. Visual Analysis and Discussion

This section provides an in-depth exploration of research on carbon emissions in e-commerce last-mile delivery through visualisation-based analyses, including keyword co-occurrence, keyword evolution, and co-citation analyses. Using VOSviewer and CiteSpace, the study examines research hotspots, development trends, and the field's knowledge structure, identifying core themes, key publications, and major scholarly clusters. The results offer insights into the evolution of the research, its methodological foundations, and potential directions for future studies.

5.1. Keyword Co-occurrence Analysis

This section uses keyword co-occurrence analysis to reveal relationships and clusters among keywords, identifying core themes and emerging research hotspots in the field.

As concise representations of a paper's core ideas, keywords play a crucial role in identifying research hotspots within a scientific field. In this study, the VOSviewer tool was employed to perform a keyword co-occurrence density mapping based on 262 selected publications. VOSviewer is a widely recognized software tool for constructing and visualizing bibliometric networks. In this study, only keywords that occurred at least 5 times were included in the visualization (Udin & Dananjoyo, 2025). The resulting map is shown in Figure 7.

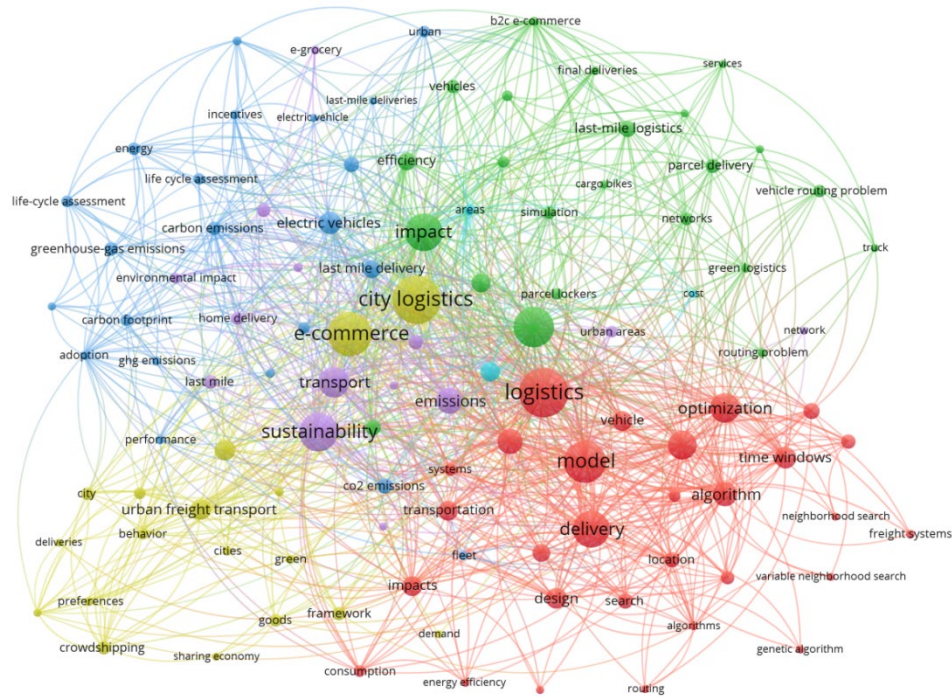


Fig. 7: Keyword Co-occurrence Network

In Figure 7, larger nodes indicate higher keyword frequency. Keywords such as logistics, city logistics, e-commerce, sustainability, last mile, and delivery appear frequently, showing sustained attention to last-mile delivery and sustainable logistics. From a service science perspective, these keywords reflect not only transport activities but also last-mile delivery as a service system involving customer participation. Keywords related to carbon emissions, such as carbon emissions, CO₂ emissions, and greenhouse gases, are scattered, suggesting that environmental concerns are recognized but not yet fully integrated with service processes and value co-creation.

Keyword changes over time reflect structural changes in logistics systems and ongoing reconfiguration of service systems. Urbanization increases logistics demand in cities, making it a focus of research. E-commerce platforms create frequent, fragmented delivery needs, increasing the prominence of “e-commerce” and “last mile delivery,” highlighting trade-offs between service frequency, customer immediacy, and environmental performance. Policies promoting electrification and green transport drive research on low-carbon delivery, but studies also show the need to balance service quality, responsiveness, and operational costs.

Digital innovations such as route optimization algorithms, smart delivery points, and drone delivery improve efficiency and reshape customer interactions. Research on parcel lockers, community pickup points, and delivery time windows reflects service system reconfiguration. These innovations enhance convenience and flexibility while reducing repeated deliveries and unnecessary trips, aligning service experience with carbon reduction.

Topics including route optimization, vehicle selection, drone delivery, and delivery point layout address both carbon mitigation and service design. Ramírez-Villamil et al. (2023) show that emissions prompt the redesign of delivery networks and that regional optimization reduces travel distance and environmental impact, reflecting service process redesign. Ouhader and El Kyal (2017) demonstrate that coordinating warehouse location and vehicle routing lowers CO₂ emissions and improves service efficiency. Bányai (2022) shows drone-integrated first-mile/last-mile delivery reduces energy use and emissions while changing customer interactions.

Overall, keyword co-occurrence analysis highlights research hotspots and evolving trends in last-

and cost structures, requiring a balance between customer satisfaction and emission-reduction goals.

Since 2016, research has increasingly addressed low-carbon transformation in e-commerce, with urban logistics serving as a central framework (Giordano et al., 2018). During 2019–2020, research activity intensified and focused on alternative delivery modes, including electric vehicles, bicycles, autonomous vehicles, and crowdsourced delivery (Rossolov et al., 2020). Drone delivery and aerial logistics also gained attention (Figliozzi, 2020). These innovations not only introduced new transport technologies but also reshaped interactions between customers and delivery systems. They enhanced flexibility and convenience while influencing carbon emission levels.

Since 2021, greater attention has been given to urban delivery infrastructure, including distribution centers, smart parcel lockers, and autonomous delivery robots (Ramírez-Villamil et al., 2023). These developments can be understood as forms of service system reconfiguration. Smart lockers, pickup points, and delivery time windows change how customers receive parcels and reduce repeated delivery attempts and empty trips. In doing so, they improve service experience and lower energy use and carbon emissions, supporting the joint improvement of service and environmental performance.

By 2024, research has expanded beyond comparisons of delivery systems across retail formats (Beziat & François, 2024) to include individual-level low-carbon behavior and sustainable consumption preferences (Nijssen et al., 2023). This shift suggests that last-mile carbon mitigation research is moving from a primary focus on technology and infrastructure toward a broader framework that emphasizes customer behavior and service experience. Overall, the evolution of keywords reflects changes in policy, technology, and urban development, and illustrates the ongoing transformation of last-mile delivery as a service system in terms of service design, service experience, and service performance.

5.3. Co-Citation Analysis

This section employs co-citation analysis to identify the core publications and key knowledge bases in the field, revealing the research clusters within the academic network.

The objective of co-citation analysis is to identify the most frequently cited journals in the research field and to determine the main publication outlets for relevant literature. Using VOSviewer, a co-citation mapping of journals was conducted. The minimum citation threshold was set at 30, resulting in the selection of 54 journals included in the analysis. The co-citation network visualisation is presented in Figure 9.

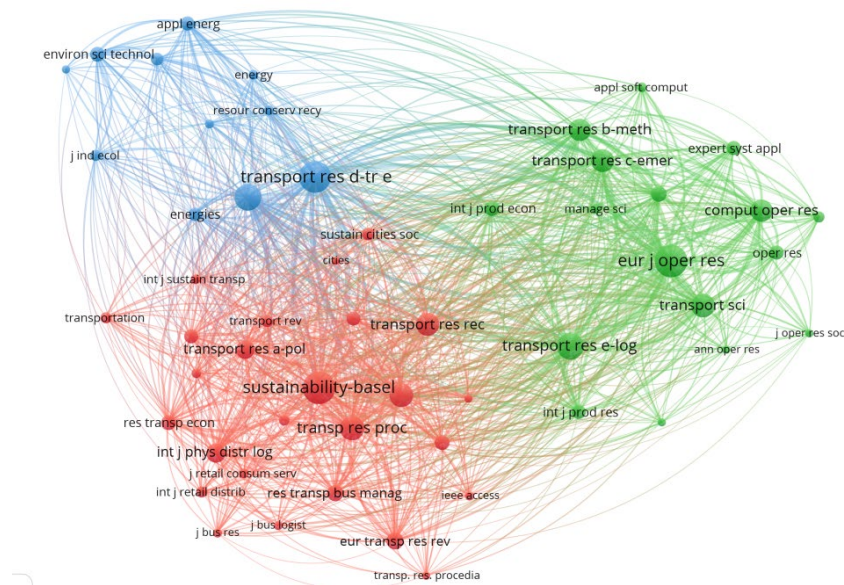


Fig.9: Co-citation of cited journals

As shown in Figure 9, the co-citation network consists of three major clusters, each represented by

a different colour, indicating distinct knowledge bases within the research domain. The top three co-cited core journals are Sustainability (co-cited 488 times, JCR Q2), European Journal of Operational Research (co-cited 479 times, JCR Q1), and Transportation Research Part D: Transport and Environment (co-cited 461 times, JCR Q1). These highly co-cited journals constitute key theoretical and methodological foundations for this field, reflecting major research focuses on operations optimisation, environmental impacts of transportation, and sustainable development.

To further explore the knowledge base of this research domain, a detailed analysis of the most frequently co-cited articles between 2010 and 2022 was conducted. Utilising VOSviewer, the top five highly co-cited references were identified, as shown in Table 5. These publications, authored by scholars such as J. Allen, J.B. Edwards, L. Ranieri, J.R. Brown, and E. Morganti, come from diverse academic backgrounds and institutions. Their studies primarily focus on logistics and supply chain management, urban logistics, last-mile delivery, and carbon emission mitigation.

Table 5. Top 5 most important publications

Rank	Title	Year Citations
1	Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: The case of London	2018
2	Comparative analysis of the carbon footprints of conventional and online retailing: A “last mile” perspective	2010
3	A review of last-mile logistics innovations in an externalities cost reduction vision	2018
4	Carbon emissions comparison of last-mile delivery versus customer pickup	2014
5	The impact of e-commerce on final deliveries: alternative parcel delivery services in France and Germany	2014

Next, a co-citation analysis of references was conducted using VOSviewer. The minimum citation threshold for references was set to 10, resulting in 99 papers being included in the co-citation analysis. The resulting co-citation network of cited references is visualised in Figure 10.

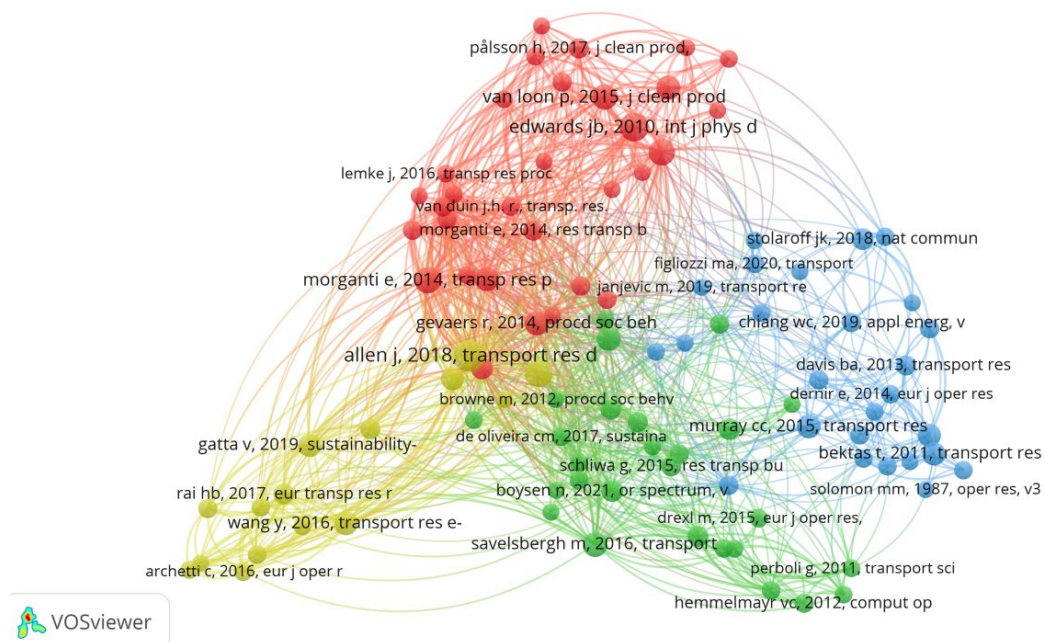


Fig.10: Co-citation of cited references

Figure 10 presents the co-citation network of highly cited references. The network can be grouped into four major clusters, each represented by a distinct colour.

The red cluster includes early foundational studies such as Edwards JB (2010) and Morganti E (2014). This cluster focuses on the environmental impacts of failed urban deliveries, sustainable urban logistics models, and the pressure placed on urban transport systems by rapid e-commerce growth. Research in this group examines last-mile service systems under increasing demand and service performance challenges, including delivery failures and delays. The emphasis is on identifying structural weaknesses in urban logistics systems rather than on specific carbon reduction technologies. Most studies adopt descriptive and empirical approaches, and information technology plays a supporting role. As the largest and most central cluster, it provides the knowledge foundation for subsequent research on low-carbon last-mile logistics.

The green cluster features studies by Savelsbergh, M. (2016) and Drexl, M. (2015). It concentrates on vehicle routing optimisation, delivery scheduling, and applications of the travelling salesperson problem in last-mile contexts. This stream of research aims to enhance delivery efficiency through algorithm design and modelling techniques. Improved operational efficiency reduces energy use and emissions. The methodological foundation lies mainly in operations research and decision support systems. Compared with the red cluster, the focus shifts from problem identification to efficiency improvement supported by information systems.

The blue cluster includes Figliozzi, MA (2017, 2020) and Stolaroff, JK (2018). It centres on electric vehicle deployment, fuel consumption measurement, and carbon emission assessment and control. This cluster highlights emission reductions through the substitution of transport technologies, particularly by adopting cleaner vehicle fleets. Studies typically rely on data-driven environmental performance evaluation and scenario analysis. The research orientation moves beyond operational efficiency towards technology-based emission mitigation.

The yellow cluster comprises studies such as Gatta V (2019) and Rai HB (2017). It addresses user behaviour, crowdsourced delivery models, and policy interventions. This line of research focuses on service model innovation and platform-based coordination. It explores how flexible delivery options, crowdsourcing mechanisms, and regulatory measures can balance service quality and carbon reduction goals. Analytical approaches often combine platform data and behavioural analysis. The cluster reflects increasing attention to integrated low-carbon logistics systems characterised by service design and user participation.

Overall, no single dominant core cluster is observed. The relative balance in node size suggests that research on carbon emissions in e-commerce last-mile delivery is still in its early stages. Multiple research trajectories progress in parallel, including structural problem identification, algorithm-based optimisation, technology substitution, and service model innovation. Together, these clusters illustrate the field's continuous evolution under the growing influence of information systems and digital technologies.

6. Conclusion and Prospects

6.1. Conclusion

Research on carbon reduction in e-commerce last-mile delivery extends beyond conventional transport or environmental concerns. It reflects a broader issue within an information-enabled logistics service system. The topic connects logistics system design, data-driven decision support, service operations management, and sustainable development. As e-commerce expands and cities face increasing pressure to decarbonise, last-mile delivery has evolved from a transport function into a systemic challenge shaped by platform coordination, algorithm-based optimisation, and service design decisions.

Using data from the Web of Science Core Collection, this study applies VOSviewer and CiteSpace

to conduct a bibliometric analysis of publications from 2008 to 2024. The analysis examines the field's knowledge structure and thematic development. Three main contributions can be identified.

At the level of knowledge structure, the results show that no highly concentrated core author group or stable theoretical centre has yet formed. Author collaboration networks, institutional distribution, journal outlets, and keyword patterns indicate strong interdisciplinary characteristics and a problem-oriented orientation. This dispersed structure reflects the relatively recent emergence of low-carbon last-mile logistics as a research topic. The field currently operates at the intersection of logistics, information systems, and sustainability studies. The diversity of publication venues suggests that the topic is still undergoing theoretical consolidation rather than being anchored within a single disciplinary tradition.

At the thematic level, keyword co-occurrence and temporal analysis reveal a clear progression. Early research focused on emission measurement and operational efficiency. Subsequent studies examined routing algorithms, electric vehicle adoption, drone delivery, and distribution network restructuring. More recent research addresses service model reconfiguration, platform governance, individual low-carbon behaviour, and sustainable consumption preferences. This evolution indicates a gradual shift from an efficiency-centred perspective towards a more integrated framework that combines technological solutions, behavioural factors, and service system design.

From a theoretical perspective, carbon emissions in the last mile can be understood as outcomes of service design choices, information flow organisation, and decision support mechanisms. Operational decisions, such as delivery time windows, instant delivery commitments, and return policies, directly influence emissions levels. Carbon mitigation, therefore, depends not only on technological substitution, including electric vehicles, but also on the structural optimisation of logistics service systems and on strengthened data-driven decision-making capabilities.

The findings offer practical implications for both managers and policy-makers. Logistics firms should incorporate carbon reduction objectives into the overall design of their service systems. Through data analytics and intelligent scheduling, firms can optimise delivery time windows, order consolidation, and route planning. Investment in informatics tools and decision support systems—such as real-time routing algorithms, Internet of Things monitoring platforms, demand forecasting models, and collaborative delivery platforms—can improve resource utilisation and reduce empty mileage.

At the policy level, urban authorities can facilitate low-carbon transitions by supporting smart parcel lockers, community pick-up points, shared distribution networks, and digital regulatory platforms. Such measures can enhance service efficiency while contributing to emission reduction goals.

Overall, research on carbon reduction in e-commerce last-mile delivery remains in a structured development phase. By conceptualising the issue as an information-enabled logistics service system, this study provides a stage-based knowledge map and an integrated analytical perspective. The results serve as a foundation for further theoretical refinement and empirical investigation.

6.2. Limitations and Outlook

This study aims to provide a systematic overview of the knowledge structure and development path of carbon reduction research in e-commerce last-mile delivery. However, several limitations should be acknowledged.

The analysis is based solely on the Web of Science Core Collection (WoSCC). Although WoSCC offers strong interdisciplinary coverage, other databases such as Scopus, Google Scholar, and regional indexing systems were not included. This may limit the scope of the literature reviewed. In logistics and transport studies, Scopus often provides broader journal coverage, which may influence publication patterns, thematic distribution, and citation structures. The findings should therefore be interpreted within the constraints of database selection. Future research could compare results derived from WoS with those from Scopus or other databases to examine the impact of database choice on bibliometric outcomes and to improve data completeness.

Bibliometric analysis relies on objective citation networks, yet the interpretation of keyword clusters, thematic categories, and research trends inevitably involves researcher judgment. To strengthen reliability, future studies may combine bibliometric findings with theoretical frameworks, policy analysis, and empirical validation. Such integration would enhance analytical depth and scientific robustness.

Several directions for future research can be identified. First, integrating multiple databases and cross-regional datasets would strengthen the comprehensiveness of knowledge mapping. Second, combining bibliometric techniques with case studies and empirical research would clarify how information-enabled logistics service models influence carbon performance in real-world settings. Third, multi-level analytical frameworks could be developed to incorporate technological optimisation, platform governance mechanisms, and consumer behaviour within a unified structure. Closer collaboration across logistics, information systems, and service science may further support theoretical development and methodological refinement.

Research on carbon reduction in e-commerce last-mile delivery remains in its early stages. By conceptualising the topic as an information-enabled logistics service system, this study provides a structured knowledge map and a stage-based synthesis of the field. The nature of bibliometric methodology constrains the conclusions and should be viewed as a foundation for further inquiry rather than as definitive causal evidence.

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Author Contributions

XH.W. was responsible for conceptualisation and led the methodological design; ZBMT contributed to data analysis and other research-related tasks; SK assisted with software implementation, formal analysis, and survey administration. All authors have read and approved the final version of the manuscript for publication.

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