Journal of Science and Technology – Engineering and Technology for Sustainable Development
Volume 36, Issue 3, July 2026, 104–114

Reducing Greenhouse Gas Emissions in Delivery Activities in E-Commerce: A Literature Review

Nguyen Ha Minh Tri, Tran Thi Huong*, Vu Manh Dat, Nguyen Trong Khoi
School of Economics and Management, Hanoi University of Science and Technology, Ha Noi, Vietnam
**Corresponding author email: huong.tranthi@hust.edu.vn*

Abstract

E-commerce has expanded rapidly, reshaping consumer behavior and logistics systems while creating significant environmental challenges. Delivery activities, especially last-mile transport, packaging waste, and energy use in digital infrastructure, contribute notably to rising greenhouse gas emissions(GHG). This study reviews 174 peer-reviewed articles to examine how emissions from e-commerce logistics can be reduced. The analysis identifies five key themes. First, delivery operations and packaging are major emission sources. Second, drivers of reduction include stricter government regulations, emerging technologies, and corporate sustainability strategies. Third, adoption of green logistics faces obstacles such as high investment costs, limited infrastructure, weak regulatory frameworks, and low consumer acceptance. Fourth, government policies, including subsidies, waste management rules, and promotion of electric vehicles, play a decisive role in shaping practices. Finally, a range of mitigation solutions is highlighted, including electric and alternative vehicles, drones, parcel lockers, reusable packaging, and consumer behavior changes. By integrating bibliometric mapping with Research Focus Parallelship (RFP) and Keyword Co-occurrence (KCO) methods, this study consolidates fragmented knowledge and provides a clearer view of current research trends. The findings offer practical insights for policymakers, businesses, and researchers seeking to design effective and sustainable e-commerce delivery systems.

Keywords: E-commerce, greenhouse gas emissions, last-mile delivery, logistics, sustainability.

1. Introduction

In recent years, the global economy has continued to grow despite geopolitical uncertainties and fluctuating market conditions. According to the World Bank, global Gross domestic product (GDP) increased by 2.6% in 2024 [1], while the International Monetary Fund (IMF) reported a growth rate of 3.3% [2], indicating a relatively stable recovery of the world economy. One of the major drivers of this growth is the rapid expansion of e-commerce, which reached USD 6.3 trillion in revenue in 2024, accounting for 20.1% of total global retail sales and projected to exceed 25% by 2027 [3]. However, alongside economic development, environmental challenges-particularly air pollution and rising greenhouse gas (GHG) emissions, have become increasingly severe. In response to the escalating impacts of climate change, more than 140 countries at the COP26 Conference pledged to achieve net-zero emissions by 2050, aiming to keep the global temperature increase below 1.5 °C.

The rapid growth of global e-commerce has significantly transformed logistics and delivery operations. With e-commerce revenues reaching USD 6.3 trillion in 2024, the volume of online orders has risen sharply, driving a corresponding surge in delivery demand. World Economic Forum study projects that the same-day delivery segment will expand at an annual rate of 36% through 2030, while instant delivery services are expected to grow by 17% per year [4]. Meanwhile, the global e-commerce sector is forecast to grow at a rapid pace of approximately 8% annually during the period 2020-2025 [5], placing substantial pressure on urban logistics systems. However, delivery activities in e-commerce represent a major source of GHG emissions. The World Economic Forum (2024) [4] warns that, without effective interventions, CO_2 emissions from urban delivery could rise by 32% by 2030, largely driven by the continued expansion of online shopping.

Multiple stages in the delivery process contribute to the increase in emissions, including packaging [6], warehousing and information and communication technology (ICT)-related energy consumption [7], failed deliveries, and product returns [8]. According to Sarkar [9], logistics, transportation, and packaging together account for up to 85% of the total GHG emissions associated with e-commerce. As a result, this topic has attracted increasing academic attention. Researchers have examined environmental impacts associated with delivery operations [10, 11] and proposed various mitigation strategies, such as electric and alternative vehicles [12, 13] drones and autonomous robots [14, 15], parcel lockers and collection points [16], and reusable packaging systems [17].

p-ISSN 3093-3242
e-ISSN 3093-3579
https://doi.org/10.51316/jst.191.etsd.2026.36.3.14
Received: Oct 7, 2025; Revised: Dec 9, 2025;
Accepted: Dec 16, 2025; Online: Jan 6, 2026

In this context, this study aims to provide three main contributions to the literature on sustainable e-commerce delivery. First, it provides a comprehensive and up-to-date review of greenhouse gas emission reduction in e-commerce delivery by synthesizing 174 peer-reviewed studies published between 2000 and 2024. Second, by integrating bibliometric mapping with research fronts and prominent topics (RFP) and keyword co-occurrence (KCO) analysis, the study offers a structured and systematic understanding of key research themes and their interconnections. Third, the review moves beyond descriptive classification by identifying critical research gaps, trade-offs, and tensions. Based on these findings, the paper also suggests potential directions for future research to help advance understanding and support the development of more sustainable delivery systems for e-commerce.

The structure of this paper includes 5 main parts: The first part is Introduction. The second one is Literature. The third part is Methodology The following is Results and Discussion and the final part of this paper is Conclusion

2. Literature Review

Recent studies have highlighted the environmental impact of delivery activities in e-commerce, emphasizing the significant role of transportation modes and operational strategies in GHG emissions.[18] conducted a comprehensive literature review to develop a taxonomy of sustainable practices in last-mile logistics for e-retail. Using a systematic review of 72 articles published between 2019 and 2023 and applying the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework, the study categorized sustainability practices into three main processes: fulfillment, transportation, and delivery modalities. In total, 31 practices were identified, including consolidation centers, shared micro-depots, shared freight transportation, electric vehicles such as bicycles and tricycles, and collection and delivery points. The study highlights the potential of these practices to reduce emissions, alleviate congestion, and improve quality of life in urban areas while also enhancing operational efficiency. However, the study is focused on developed countries, has insufficient discussion of implementation challenges, limited attention to social aspects of sustainability, and the absence of direct quantification of greenhouse gas reductions.

The growth of e-commerce also generates a significant amount of waste through packaging used for deliveries [19]. A systematic review of the literature from 2011 to 2020 revealed five key objectives of packaging sustainability guidelines: Optimizing resources, responsible sourcing, resource recovery, material health, and consumer engagement. The most widely adopted waste reduction strategy was designed for the environment under the optimizing resources guideline. This study is the first to clearly identify and articulate guidelines, policies, and practices to support policymakers and industry stakeholders in addressing transport packaging waste in e-commerce. Nevertheless, it did not analyze literature published after 2020, leaving a gap in the current strategies for managing e-commerce packaging waste.

Another study employing a literature review on carbon-neutral delivery in Vietnam's e-commerce context highlights both the potential and the challenges of adopting such solutions in the country's rapidly expanding e-commerce sector. Although carbon-neutral delivery is increasingly adopted worldwide, especially in developed markets, there is still little research on how it can be applied in emerging economies such as Vietnam. Most existing studies emphasize the environmental impacts of logistics in advanced nations, while paying insufficient attention to the distinct economic, infrastructural, and cultural challenges present in developing contexts [20].

To advance research on sustainable e-commerce logistics and develop a comprehensive understanding of effective mitigation strategies, consolidating previous research findings is essential. Therefore, we adopt a bibliometric and content analysis to explore recent studies on the environmental impacts of delivery activities, focusing on greenhouse gas emissions. Effective mitigation strategies should be examined in both developed and developing country contexts, recognizing differences in infrastructure, resources, and policy frameworks.

3. Methodology

This study adopts a systematic and structured methodological approach to review, analyze, and synthesize the existing body of literature on greenhouse gas emissions in e-commerce delivery activities. The methodology consists of four main components: (i) research design, (ii) data sources and search strategy, (iii) screening and selection criteria, and (iv) analytical methods integrating RFP and KCO.

3.1. Data Collection

Scopus was selected as the primary database due to its extensive coverage of peer-reviewed journals across disciplines relevant to logistics, sustainability, and management. A three-level keyword formulation was applied to build search strings. **At the first level**, we used terms related to emission reduction such as *"reduc*", "mitigat*", "decarbon*", "neutral*", "release*", and "eliminat*"*. **At the second level**, we included greenhouse gas–related expressions, namely *"greenhouse gas*", "GHG*", "carbon emission*", "CO2", "carbon footprint", "sustain*", and "green*"*. **The third level** contained logistics and delivery terms such as *"deliver*", "transport*", "ship*", "transit*"*. Finally, we combined these with e-commerce-related terms, including *"e-commerce", "ecommerce",* *"e-grocery", "multi-channel", "omni-channel", "online shopping", "online retailing", "e-logistics", and "e-retail"*.

The initial search generated **621 hits**. To refine the dataset, several inclusion criteria were applied. First, we limited the subject areas to *Business, Management and Accounting; Economics, Econometrics and Finance; Environmental Sciences; Energy; and Social Sciences*. This step reduced the dataset to **332 articles**. Secondly, only studies published in peer-reviewed academic journals were retained and conference papers, book chapters, editorial notes, and non-academic sources were rejected to ensure the quality of the selected articles, resulting in **221 articles**. Third, we excluded non-English publications, yielding **219 articles**.

A final relevance assessment was then conducted, where abstracts and, when necessary, full texts were reviewed to exclude papers not explicitly focused on reducing greenhouse gas emissions in delivery activities within the e-commerce context. After this screening, the final dataset comprised **174 articles**, which were used for further bibliometric and content analysis.

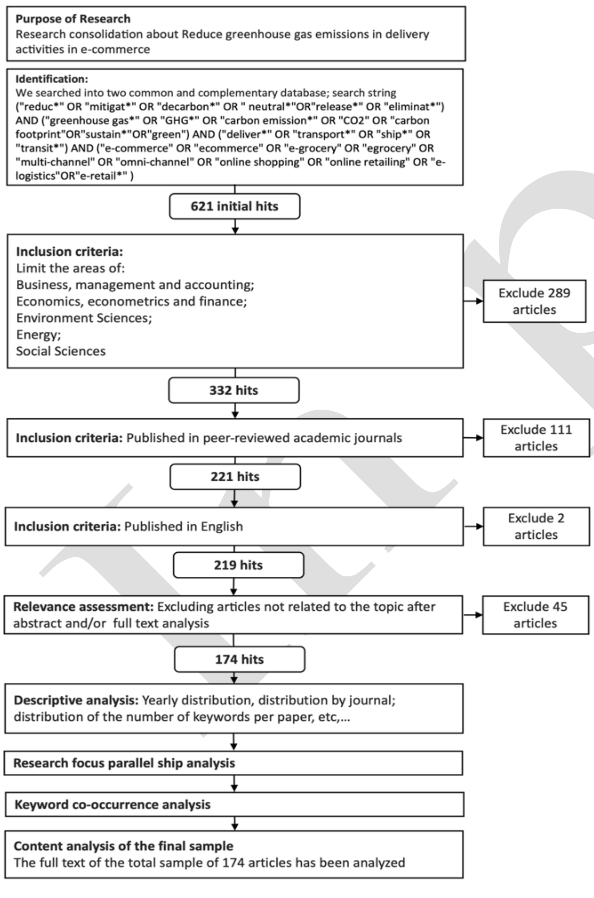

Fig.1. Methodology for integrated systematic review

3.2. Keyword Network Mapping

To explore the intellectual structure of the field, we applied a bibliometric keyword analysis. Following the framework of Su and Lee [21], the procedure consisted of several steps: (i) extracting the raw data, (ii) revising and producing descriptive statistics of keywords, (iii) calculating the properties of the network, and (iv) visualising the resulting knowledge map. The final dataset of 174 papers was exported from the databases in plain text format and processed using VOSviewer and R-studio for bibliographic analysis and data transformation. Prior to analysis, the keywords were standardised to ensure consistency. This included converting plurals into singular forms, merging synonyms and aligning abbreviations with their full terms (e.g., "GHG emission" with "greenhouse gas emission"). Careful preparation of the dataset, complemented by keyword screening and full-text checks performed by two researchers, helped mitigate risks of misinterpretation.

3.3. Research Focus Parallelship

The RFP approach [22] was employed to examine how articles are related through their use of common keywords. The underlying assumption is that if two studies share at least one keyword, their research themes may overlap, indicating a degree of parallelism in focus. Such overlaps reveal potential linkages within the broader research landscape, suggesting that the content of these studies addresses similar aspects of the topic. By mapping these connections, RFP highlights clusters of research and provides insight into how individual contributions relate to one another.

3.4. Keyword Co-Occurrence

KCO analysis was further applied to capture the relationships between terms that frequently appear together across the dataset. This process starts with extracting keywords from each paper, constructing a co-occurrence matrix that records the frequency of joint appearances, and translating the results into a network graph where nodes represent keywords and edges indicate their co-occurrence strength. The resulting map allows for the identification of keyword clusters, the recognition of emerging topics, and the examination of the structural evolution of the field. KCO analysis is therefore instrumental in illustrating the interconnections among themes, uncovering new directions for research, and providing a longitudinal perspective on scholarly developments.

3.5. Integrated Research Fronts and Prominent Topics and Keyword Co-Occurrence Method

Given the fragmented and multidisciplinary nature of research on greenhouse gas emission reduction in e-commerce delivery, relying on a single bibliometric technique may be insufficient to fully capture both thematic structures and inter-study relationships. Therefore, this study combines RFP and KCO analysis, as this integrated approach is particularly suitable for mapping a complex research domain that spans logistics operations, environmental sustainability, policy instruments, and technological innovation.

RFP enables the identification of parallel research streams by examining overlaps in keyword usage across studies, thereby revealing how individual articles converge around similar research focus. This is especially relevant for the present topic, where studies often address similar emission-reduction issues from different disciplinary perspectives. Meanwhile, KCO analysis captures the frequency and strength of associations among keywords, allowing for the detection of dominant themes, emerging topics, and their structural evolution over time.

Compared with conventional bibliometric methods such as publication counts, citation analysis, or co-citation analysis, the integrated RFP–KCO approach extends analytical depth in two important ways. First, while traditional bibliometric indicators mainly reflect research productivity and academic influence, RFP focuses on thematic parallelism, enabling a finer-grained understanding of how research topics overlap and interact across studies. Second, KCO complements this by visualizing the semantic structure of the field, highlighting not only well-established themes but also underexplored or emerging research directions.

By integrating these two methods, the present study can bridge micro-level connections between individual articles and macro-level thematic patterns across the literature. This combined approach thus provides a more comprehensive synthesis than conventional bibliometric reviews that rely on a single analytical technique.

4. Results and Discussion

4.1. Descriptive Analysis

4.1.1. Distribution of reviewed papers by year

Fig. 2 illustrates the yearly distribution of the selected articles. The first study on this topic was published in 2000, followed by very limited activity for more than a decade, with only a few publications and several years without any output.

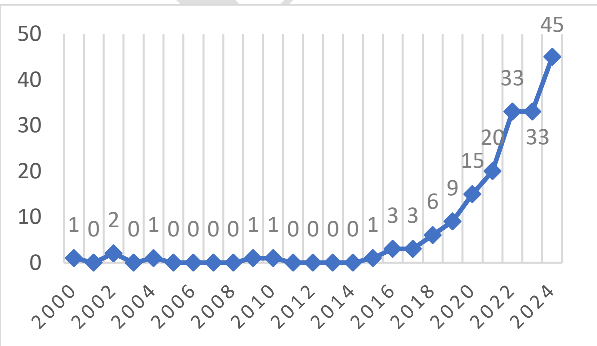

Fig. 2. Distribution of reviewed papers by year

From 2015 onwards, the number of studies began to increase gradually. A clearer growth trend is visible after 2018, with the annual number of publications rising steadily. In 2020 and 2021, the dataset records 15 and 20 papers, respectively.

The upward trend continued in subsequent years, with 33 articles published in both 2022 and 2023, and reaching the highest point in 2024 with 45 papers.

4.1.2. Distribution of reviewed papers by the journal

All 174 reviewed papers were published in a variety of journals. The top journals with the highest number of contributions are presented in Fig. 3. Among them, Sustainability (Switzerland) published the most articles from the dataset (35 papers). This is followed by the Journal of Cleaner Production (15 papers) and Transportation Research Part D: Transport and Environment (10 papers).

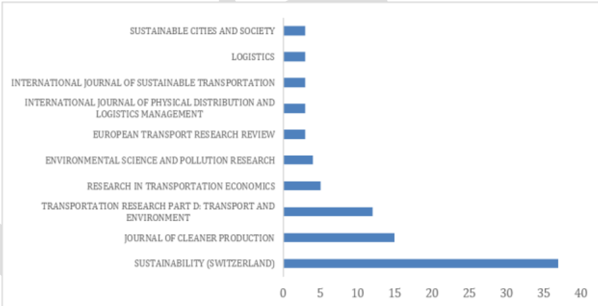

Fig. 3. Distribution of reviewed papers by the journal

4.1.3. Distribution of reviewed papers by authors

This review comprised 174 papers from multiple countries worldwide. Fig. 4 indicates the top contributing countries to this topic. Notably, China has the highest number of publications, with 37 papers. The USA ranks second with 17 papers, followed by Italy with 12 papers. Other countries with a smaller but still relevant contribution include Brazil (8 papers), Spain (7 papers), and India (6 papers). In addition, Belgium, the Netherlands, and the United Kingdom each contributed five papers to the dataset.

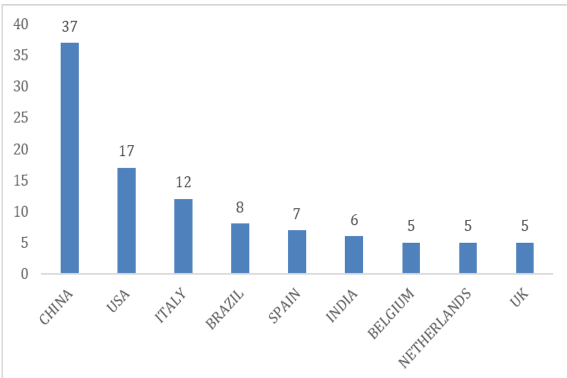

Fig. 4. Distribution of reviewed papers by authors

4.1.4. Keyword frequency

The accompanying word cloud provides a visual representation of the most frequently used keywords by researchers in this field. The most prominent terms include "electronic commerce", "sustainability", and "sustainable development", followed by "carbon emission", "environmental impact", "carbon dioxide", "emission control", "logistics", and "last-mile delivery". These recurring terms indicate diverse strategies proposed for achieving more sustainable e-commerce logistics while reducing GHG emissions.

Fig. 5 further shows that the keywords can be grouped into three major aspects of the topic: (i) technology and operations (e.g., "last mile" "optimization", "vehicle routing"), (ii) e-commerce and logistics (e.g., "online shopping", "city logistics", "supply chains"), and (iii) environmental sustainability (e.g., "carbon footprint", "environmental economics," "greenhouse gases"). Among these, keywords associated with sustainability and carbon emission reduction appear most prominently, highlighting the central focus of the reviewed studies on addressing environmental impacts.

Fig. 5. Keyword frequency in Research on green technologies applied to reduce GHG Emissions in the Shipping Industry

4.1.5. Trend topics

Fig. 6 illustrates the distribution of trend topics over time. The keywords can be organized into several groups with similar or overlapping meanings as following.

- **Internet**: This was the earliest topic, appearing in 2012, but it did not continue in subsequent years.

- **Commerce, Sales**: These terms appeared between 2019 and 2021, reflecting discussions related to commercial activities and retail demand within e-commerce.

- **Freight transport, City logistics, Carbon emission**: This group of topics gained attention from 2020 onwards. Research under these keywords highlights transportation activities in urban areas and their associated emissions.

- **Sustainability, Sustainable development**: Both terms became frequent after 2020, emphasizing the integration of environmental concerns and long-term development objectives in e-commerce logistics.

- **Electronic commerce, Online shopping**: These keywords have been dominant since 2020, representing the core research domain on digital retail platforms and online consumer behavior.

- **Last mile, Last-mile delivery**: Beginning in 2020, these closely related terms indicate the strong research focus on the final stage of distribution, where environmental impacts are most critical.

- **Consumption behavior, E-commerce**: These more recent topics emerged after 2021. "Consumption behavior" reflects the demand-side perspective, while "e-commerce" has appeared since 2023, extending into 2024.

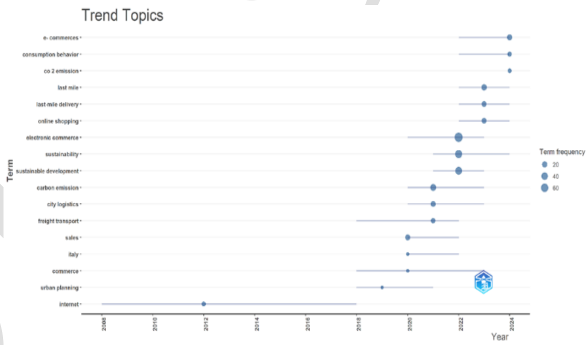

Fig. 6. Trend Topics on Reducing GHG Emissions in delivery activities in e-commerce

4.2. Content Analysis, Parallelship, and Keyword Co-Occurrence Analysis

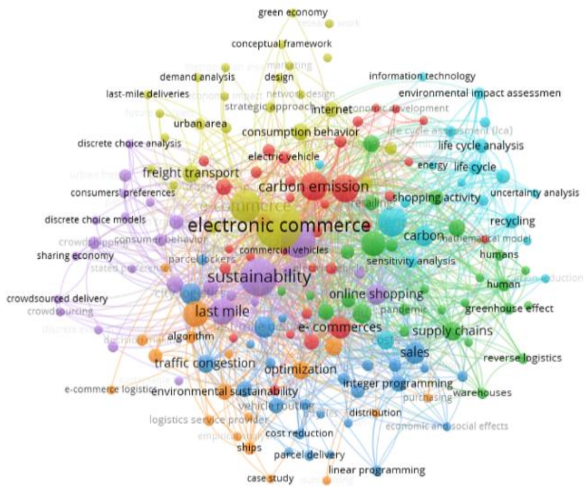

Fig. 7. Five clusters on reducing GHG emissions in delivery activities in e-commerce

4.2.1. Cluster 1: Environmental impact of e-commerce

Research on the environmental impacts of e-commerce has been conducted since the early 2000s, focusing on key aspects such as packaging, transportation, energy consumption, and information flows. E-commerce generates significant CO_2 emissions during the distribution of goods, whether by rail, air or road transport, while the reverse logistics, generated by the return and exchange of goods, also increases carbon emissions. In addition, e-commerce packaging predominantly relies on non-renewable materials, while returned goods are often disposed of instead of being recycled or resold. These practices intensify the environmental footprint of business-to-consumer online retailing. Studies [6, 10, 23-24] indicate that the environmental effects of express delivery package waste (EDPW) are generally minor across most categories, with the exception of global warming potential and human toxicity, which are largely driven by energy and material use in packaging production. From a carbon footprint perspective, handling 1,000 kg of EDPW results in 834.88 kg CO_2-eq emissions from raw material manufacturing, while material and energy recovery can offset about 524.55 kg CO_2-eq.

A study by Long [25], based on survey data from 6,000 households, calculated the carbon footprint of online consumption, identifying electricity, clothing, and beauty products as the main contributors. The garment industry, one of the earliest and largest sectors in e-commerce, is expected to exert growing environmental pressures as the “fast fashion” trend continues to expand. Muñoz-Villamizar [26] investigated the sustainability implications of fast shipping. Using a discrete-event simulation model validated with the largest retailer in Mexico, the study examined the effects of delivery windows, inventory policies, and truck types on environmental performance. The findings reveal that fast shipping hampers cargo consolidation, resulting in significantly higher CO_2 emissions and costs up to 15% and 68% respectively, thereby highlighting the trade-off between service speed and environmental sustainability. According to Sarkar [9], the maximum GHG emissions increased from logistics, transportation, and packaging (85% of total GHG emissions in 2020).

E-commerce generates GHG emissions mainly from transportation, packaging, warehousing, and the energy demand of ICT infrastructure. These emissions contribute to global warming, air pollution, and related health problems. Although online shopping can reduce certain emissions associated with physical retail, overall impacts often rise due to additional delivery trips, inefficient logistics, and packaging waste, with last-mile delivery representing a particularly critical source of emissions [27].

E-commerce operations consume substantial energy to run servers, data centers, and related infrastructure. This high energy use results in elevated greenhouse gas emissions, which contribute to climate change. According to Samuel Eapen [7] , a study estimates that the carbon footprint of e-commerce is approximately 30% greater than that of conventional retail. Another environmental drawback of e-commerce is the rise in packaging waste. Since products are frequently delivered directly to consumers, extra packaging materials are needed. This increase in packaging contributes to the escalating issue of plastic pollution, which poses serious environmental challenges. E-commerce packaging waste will reach 22 million tons by 2025.

4.2.2. Cluster 2: Drivers for emission reduction

Cluster 2 addresses the driving forces behind GHG emission reductions in the transport and logistics sectors, with studies spanning from 2019 to 2024. More recently, the drivers of emission reduction have come from government policies and international sustainability regulations. For example, Zang [28] highlight China’s carbon peak (2030) and neutrality (2060) targets as strong policy drivers, while emphasizing the role of freight demand uncertainties, the rapid expansion of e-commerce, and the advancement of technologies such as hydrogen-fueled heavy trucks and modal shifts as critical forces driving emission reductions. Oliveira [29] highlighted that the transition toward integrated freight and passenger transport systems is strongly driven by technological advances, increasing awareness of climate change, and supportive policy initiatives such as the European Commission’s 2007 proposal. These drivers create both urgency and opportunity for reducing emissions and promoting sustainable urban logistics.

Additionally, other researchers have examined the role of corporate image and brand reputation as strong drivers of sustainable practices. For example, Kayakuş [30] demonstrate that brand reputation, rooted in quality, responsibility, and customer satisfaction, acts as a key motivator for sustainable business practices, as evidenced by their analysis of customer reviews of the iPhone 11 on Trendyol, Turkey’s largest e-commerce platform. For instance, companies operate based on sustainable business models [31] that lower CO_2 emissions, introduce sustainable products that are more durable and of higher quality, and engage in social initiatives that raise customer awareness about the advantages of green consumption while collaborating with retailers that promote eco-friendly goods.

4.2.3. Cluster 3: Barriers to implementing greenhouse gas emission reduction in e-commerce

Studies on this cluster have revealed that the adoption of emission reduction measures in e-commerce faces several barriers. Prominent challenges include high investment costs, limited technological readiness, insufficient regulatory support, and low consumer acceptance, all of which hinder the transition toward greener logistics. Boggio-Marzet [32] identify several barriers that hinder the adoption of low-emission strategies in last-mile delivery, including high investment costs, limited infrastructure that constrains the large-scale deployment of parcel lockers, micro-hubs, and electric vehicles, conflicting stakeholder priorities, and low public acceptance, all of which challenge the feasibility of sustainable delivery solutions.

Recent research has highlighted that e-commerce faces multiple barriers in implementing sustainable last-mile strategies. Drawing on desk research and semi-structured interviews with twenty Spanish e-retailers, González-Romero [17] identified twenty barriers, grouped into seven categories, including value proposition and organization, finance, retailer-customer relations, retailer-transport companies, retailer-drivers, legislation and citizens, and technology. Institutional and societal barriers include restrictive or inadequate regulatory frameworks, insufficient supportive policies, and low citizen engagement. Technological limitations such as high costs of innovations, lack of adaptability to different retail contexts, fragmented solutions across regions, and underdeveloped infrastructure (e.g., charging stations, consolidation centers) further constrain sustainable last-mile logistics.

In order to overcome existing barriers and promote the development of emission reduction solutions in online shopping, researchers have increasingly focused on identifying the underlying factors that hinder implementation. According to Sallnäs and Björklund [33] these factors can be classified in six categories: organizational, financial, technological, market (retailer-logistics service provider), market (retailer-consumer), and governmental barriers.

Related to organizational barriers, these barriers are closely linked to the degree of engagement an entire company has with sustainability. Prior studies, such as Sallnäs and Björklund [33], highlight that limited commitment from the overall organization, particularly insufficient support from top management, represents a significant obstacle to the successful implementation of sustainable last-mile strategies.

Besides the organizational barriers, the level of technological advancement is another critical factor. Castillo [34] emphasize that specific technical characteristics can strongly influence decisions on whether to adopt a given technology. Examining automation in urban deliveries, Paddeu and Parkhurst [35] identified the maturity of a technology as a major obstacle to its implementation.

Governmental barriers also play a crucial role in shaping the prospects for sustainable last-mile logistics. Achmad [36] underline the significance of introducing eco-friendly regulations. Although some innovations have received fiscal incentives in certain regions [37], scholars frequently stress that the absence of clear regulations and standards remains a major obstacle [35], [38].

4.2.4. Cluster 4: Government policy in reducing greenhouse gas emissions

The crucial role of government policy in reducing GHG emissions from e-commerce delivery has been emphasized, with some studies in this group highlighting the impact of government subsidies [39]. According to Liu [40], the Chinese government has played a central role in promoting the integration of e-commerce with environmental governance. The establishment of national e-commerce demonstration Cities is a key policy initiative in China aimed at encouraging the healthy and rapid development of e-commerce.

The government supports capital investment by companies in new equipment or infrastructure and subsidizes greener freight modes. Governments across many countries have created programs to promote adoption of good environmental practices in logistics sector. For instance, the UK's Freight Best Practice Programme (FBP) offers guidance to companies on various strategies aimed at enhancing efficiency and minimizing the environmental footprint of freight transport operations [41].

Creating sustainable e-commerce solutions depends on the active participation of all stakeholders, including governments, businesses, consumers, and the financial sector. For instance, governmental regulations and initiatives aimed at raising environmental standards are widely recognized as key drivers for initiating and implementing sustainable practices, as well as for fostering innovations in products, services, and systems [42].

In India, several regulatory measures have been introduced to mitigate emissions and waste associated with online retail. The Plastic Waste Management Rules (2016) established extended producer responsibility, requiring e-commerce companies to collect and manage the plastic waste generated from their packaging. Additionally, the FDI Policy for e-commerce [43] indirectly aimed at reducing excessive warehousing and transport-related emissions by restricting stockpiling practices. Beyond regulations, the government has encouraged platforms to adopt green initiatives such as sustainable packaging and the integration of electric vehicles into last-mile delivery [7].

4.2.5. Cluster 5: CO_2 emissions solutions in e-commerce

Recent studies on sustainable urban logistics have proposed a variety of strategies to mitigate CO_2 emissions in last-mile delivery. Most of these studies emphasize the adoption of environmentally friendly vehicles and drone delivery model [12, 13, 44] as well as the deployment of advanced digital technologies such as IoT, big data, artificial intelligence, and blockchain [45-48]. Leyerer [12] highlight the role of alternative vehicles such as electric vans, electric cars, and cargo bikes as effective substitutes for conventional diesel fleets. It emphasized the importance of establishing micro depots and urban consolidation centers near city centers to shorten delivery distances and enable the efficient use of eco-friendly vehicles. A novel last-mile delivery solution combines public transport with autonomous robots to cut emissions, traffic, and noise [15]. Bandeira [13] assess sustainable alternatives for last-mile delivery in Rio de Janeiro, focusing on replacing diesel light-duty vehicles with battery electric light duty vehicles (LDVs) and electric tricycles. The results show that electric tricycles offer the greatest benefits, reducing emissions and delivery costs by nearly 28%, while also improving worker health and productivity.

Several recent studies have proposed dual-channel green supply chain models to address GHG reduction in e-commerce transportation [49, 50]. Within the green supply chain framework, emission reduction in e-commerce can also be achieved through the adoption of reusable packaging [17], which involves the use of low-impact materials (e.g., cardboard instead of polyester), ensuring high return and reuse rates through consumer-friendly processes, and implementing decentralized supply chains to reduce transport distances.

Furthermore, some studies point out that changing consumer behavior in e-commerce also serves as an effective emission reduction measure, such as the use of parcel lockers, convenience store pick-up, automated courier stations (ACS), and low-emission delivery frameworks. A study by Peppel [16] evaluates the role of mobile parcel lockers (MPLs) in making last-mile delivery more sustainable. The research shows that MPLs can achieve cost savings of 8.7% and CO_2e emission reductions of up to 5.4%. The results highlight that MPLs are most effective in dense urban areas, while in rural regions, they may cause higher emissions due to longer customer travel distances. Li [48] clarifies how green signals influence switching behavior and highlight ACS as a viable strategy to promote environmentally friendly last-mile logistics and reduce emissions.

4.2.6. Cross-cluster synthesis

When synthesizing findings across clusters, a clear gap emerges between policy ambitions and practical implementation. While Cluster 4 highlights strong governmental commitments and policy frameworks promoting low-carbon e-commerce delivery, cluster 3 shows that high investment costs, infrastructure constraints, and limited organizational readiness continue to hinder effective implementation at the operational level. This misalignment suggests that policy support alone is insufficient without complementary financial incentives, infrastructure development, and capacity building.

Similarly, although Cluster 5 identifies a wide range of technological solutions-such as electric vehicles, drones, parcel lockers, and digital optimization toolshe persistent barriers discussed in Cluster 3 significantly limit their large-scale adoption. In particular, technological immaturity, high upfront costs, and low consumer acceptance remain critical challenges, especially in developing and emerging economies.

The literature also reveals several important trade-offs and contradictions. For example, fast and same-day delivery models, which are increasingly demanded by consumers, often conflict with emission reduction goals due to reduced consolidation efficiency and increased delivery frequency. Likewise, while advanced technologies such as drones and autonomous vehicles promise emission reductions, their environmental benefits may be offset by regulatory barriers, energy sources, and high system costs. These trade-offs indicate that emission reduction strategies in e-commerce delivery cannot be evaluated solely on technological potential, but must be assessed within broader economic, regulatory, and behavioral contexts.

5. Conclusion

E-commerce brings convenience and cost savings for both consumers and enterprises, yet it also generates significant transport-related emissions, creating mounting environmental pressures; therefore, greening e-commerce has become both an inevitable trend and an urgent requirement for sustainable development. Research on emission reduction in e-commerce delivery has been steadily expanding, highlighting that making this sector greener is both achievable and increasingly driven by technological advances, regulatory frameworks, and corporate sustainability commitments. Following an initial screening, our study employed bibliometric techniques, specifically RFP-KCO analysis, on 174 peer-reviewed articles sourced from the Scopus database. The publication trend of these 174 studies between 2000 and 2024 shows consistent growth, underscoring the rising academic attention to sustainable e-commerce logistics. Using modularity-based clustering, we further identified five dominant thematic clusters within the dataset.

The findings highlight five major thematic clusters, including the environmental impacts of e-commerce [6, 11], the drivers that encourage emission reduction [29, 51], the barriers hindering implementation [52], the pivotal role of government policy [40, 53], and a wide range of mitigation solutions [12, 16]. Among them, last-mile delivery and packaging emerge as the most significant sources of emissions, while government regulations, technological innovation, and corporate sustainability commitments serve as essential drivers of change. This study emphasizes that government policies play a decisive role in shaping sustainable e-commerce logistics, with measures such as subsidies, waste management regulations, and the promotion of electric vehicles accelerating the transition toward low-carbon solutions [37]. At the same time, enterprises are encouraged to integrate green technologies, adopt alternative delivery methods such as drones, parcel lockers, and cargo bikes, and enhance consumer awareness to foster environmentally responsible behaviors [13, 53].

From a theoretical perspective, future studies could extend the current literature by integrating sustainability transition theory, stakeholder theory, or institutional theory to better explain how policy pressure, corporate strategies, and consumer behavior jointly influence emission reduction in e-commerce delivery. Such theoretical lenses would help move beyond descriptive classifications toward explaining why certain mitigation measures succeed or fail in practice.

Methodologically, the findings of this review suggest a need for more quantitative decision-support approaches, particularly multi-criteria decision-making models (MCDM), to evaluate emission reduction solutions under multiple and often conflicting criteria, such as cost, environmental impact, technological feasibility, and social acceptance. Future research could build context-specific MCDM frameworks to support policymakers and logistics providers in prioritizing suitable solutions rather than assessing individual measures in isolation.

In terms of context, future research should pay attention to regional and regulatory differences, especially between developed and developing economies. Infrastructure availability, regulatory enforcement, market maturity, and consumer behavior vary significantly across regions, which may lead to different environmental outcomes for the same delivery solution. Comparative or region-specific studies would therefore provide more actionable insights for both policymakers and practitioners.

Although this research offers meaningful insights, several limitations must be acknowledged. First, the search criteria may have excluded certain relevant studies. Second, the scope of sources could be expanded beyond Scopus to include databases such as Web of Science, and more advanced review methods, such as quantitative content analysis or meta-analysis, could be applied. Despite these limitations, this study helps bring together scattered research on sustainable e-commerce delivery and offers practical insights for policymakers, businesses, and researchers.

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