

Green Logistics Optimization: An Operations Research Perspective

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ABSTRACT:

This study presents a bibliometric and thematic review of green logistics optimization from an Operations Research (OR) perspective. Data were retrieved from Elsevier's Scopus database and comprise 932 English-language records (880 articles and 52 reviews) published between 2014 and 2026. Publication patterns were analysed with Bibliometrix and Biblioshiny, and keyword relationships were mapped with VOSviewer. Annual output rose from 17 publications in 2014 to 188 in 2025, and an exponential trendline ($R^2 = 0.9389$) described this growth better than a linear one ($R^2 = 0.7526$). Optimisation, sustainability, supply chain management, vehicle routing and multi-objective optimisation form the intellectual core of the field, while artificial intelligence, circular economy, reverse logistics, blockchain and Industry 4.0 are emerging themes. Only 91 records (9.8%) combine simulation or benchmark testing with a case study or empirical setting, and 213 (22.9%) use uncertain, probabilistic or robust modelling, revealing a gap between model sophistication and demonstrated practical applicability.

KEYWORDS: Green Logistics Optimization; Operations Research; Bibliometric Analysis; Supply Chain Sustainability; Vehicle Routing.

1. INTRODUCTION

The environmental dimension of logistics is now recognised as inseparable from efficiency, resilience and competitiveness in global trade. Global trade in goods and services stands at around \$35 trillion in 2025, a new record, while trade flows are becoming more complex and volatile because of changing patterns, geopolitical tensions and disruptions (UN Trade and Development, 2026). Logistics systems must therefore keep delivering goods efficiently while minimising the environmental impact of transportation, warehousing, distribution, energy use and waste.

Transport is especially sensitive. It consumed approximately 30% of global energy demand in 2024, with road transport accounting for nearly 90% of domestic transport energy demand, and road-sector emissions were just over 6 gigatonnes of CO₂ in 2024, still higher than in 2015 (International Energy Agency, 2025a, 2025b). Improvement therefore requires decisions across the whole logistics chain, from vehicle selection and routing to inventory, reverse flows and energy use. Green logistics integrates environmental considerations into logistics planning and control without compromising cost, service and operational performance. It is narrower than sustainable logistics, as it is limited to the environmental impact of transportation, storage, inventory, distribution and related activities.

This complexity links Operations Research (OR) directly to green logistics. OR uses quantitative methods to support decisions and has long been applied to reduce transport costs, optimise routes, locate facilities, allocate resources, schedule deliveries and manage inventory. Green logistics adds environmental goals to these economic ones: a model may weigh cost, distance, delivery time, fuel use and carbon emissions together, and a facility-location model may include environmental impact and energy requirements alongside construction and transport costs. Network optimisation identifies efficient flows between suppliers, sites and customers; multi-objective optimisation handles conflicting objectives such as cost and emission reduction; simulation studies performance under different operating conditions; stochastic and robust optimisation incorporate uncertainty in demand, travel time and disruption; and heuristics and metaheuristics, such as genetic algorithms and particle swarm optimisation, help when exact optimisation becomes impractical. As Section 2 shows, mathematical models, most often mixed-integer linear programming (MILP), dominate the literature.

Green logistics optimization is therefore not only about making logistics “greener” but about integrating environmental aims into operational decisions without making systems economically or operationally impossible, because environmental improvements often carry costs. The circular economy and the triple bottom line (TBL) are the key concepts used to address these trade-offs. The scope now includes carbon-aware transportation, alternative-fuel and electric fleets, renewable energy, sustainable warehousing, reverse logistics, closed-loop supply chains and waste reduction, while artificial intelligence (AI), machine learning, the Internet of Things (IoT), Industry 4.0, digital twins and blockchain are changing how systems are planned, controlled and traced.

Research has developed along interrelated streams, namely vehicle routing, network design, alternative-fuel fleets, reverse logistics, digital technologies, hydrogen infrastructure, circular economy systems and resilience, but these are often studied separately. A more integrated understanding is needed, particularly because an advanced model delivers environmental benefits only if data, infrastructure, organisational skills, investment and operator willingness to adopt it are available.

The bibliometric data show rapid growth. Between 2014 and 2026, 932 English-language records were published in 416 sources by 2,597 authors, and annual output rose from 17 publications in 2014 to 188 in 2025. Combining AI, machine learning, digital twins, blockchain and Industry 4.0 with optimisation models can improve prediction, monitoring, routing, traceability and real-time decision-making, while circular approaches connect reverse logistics, recycling, reuse, remanufacturing and closed-loop supply chains. However, technological solutions can be expensive and complex, and increasingly complicated models are harder for practitioners to interpret or implement. Yet few records combine model testing with real-world evidence, pointing to a disconnect between the sophistication of optimisation models and evidence of their practical applicability (Section 5 and Section 6).

Against this background, the study examines green logistics optimization from an OR perspective to understand how the field has developed and how it is structured. A bibliometric and thematic approach was applied to Scopus records from 2014 to 2026, using Bibliometrix and Biblioshiny for publication patterns and descriptive features, VOSviewer for keyword relationships and thematic clusters, and Microsoft Excel for trend analysis. The analysis covers publications, authorship and collaboration, sources, citations, keyword occurrence and co-occurrence, thematic relations and methodological features. The review is organised as follows: the next section presents the literature review, followed by the research objectives, methodology, data analysis and results, discussion and implications, future research agenda, and conclusion and limitations.

2. LITERATURE REVIEW

Green logistics concerns the environmental cost of moving, storing and distributing goods. Dekker et al. (2012) define it as the integration of environmental considerations into logistics and show how OR can reduce emissions while exposing trade-offs between cost and environmental performance. It overlaps with sustainable logistics and sustainable supply chain management but is narrower, focusing on environmental impacts in transport, warehousing, inventory and distribution, whereas sustainable logistics applies the broader triple-bottom-line perspective (Shamsuddoha et al., 2022). Earlier reviews examine green supply chain management (Fahimnia et al., 2015), environmental concerns in logistics (Islam et al., 2021), road-freight decarbonisation (Meyer, 2020), sustainable logistics and supply chains (Wang et al., 2023) and green vehicle-routing methods (Garside et al., 2024), as summarised in Table 1. What remains limited is a recent, field-wide synthesis connecting publication trends, keyword relationships, OR methods, environmental technologies, circularity and resilience.

Authors	Scope of Review	Year
Dekker, Bloemhof & Mallidis	Aspects, issues, contributions and challenges of OR for green logistics	2012
Demir, Bektaş & Laporte	Recent research on green road freight transportation	2014
Fahimnia, Sarkis & Davarzani	Green supply chain management: review and bibliometric analysis	2015
Juan, Mendez, Faulin, de Armas & Grasman	Electric vehicles in logistics: environmental, strategic and operational challenges	2016
Meyer	Bibliometric and network analysis of decarbonising road freight transportation	2020
Islam, Moeinzadeh, Tseng & Tan	Environmental concerns in logistics: trends and future challenges	2021
Wang, Lim, Wang & Tseng	Bibliometric analysis of sustainable logistics and supply chains	2023
Garside, Ahmad & Muhtazaruddin	Solution approaches for green vehicle routing problems and variants	2024

Table 1. Summary of review articles

Conceptual foundations

Green logistics is guided mainly by two frameworks: the circular economy, which minimises waste and pollution by extending, closing and tightening material and energy loops (Lopes de Sousa Jabbour et al., 2019), and the triple bottom line, which measures environmental, social and economic impacts (Shamsuddoha et al., 2022). Kazancoglu et al. (2018) argue that green supply chain management must assess environmental, financial, logistical, organisational and marketing performance as a single entity. In practice these principles compete. A routing model that lowers emissions may lead to longer delivery times or higher costs; a reverse logistics network reduces waste but requires extra transport for collection; and an electric fleet eliminates tailpipe emissions but brings range limitations, charging-infrastructure

needs and battery constraints (Juan et al., 2016). Forward logistics sends products to customers, reverse logistics brings used items back for recycling, reuse or safe disposal, and closed-loop logistics combines both directions (Zarbakhshnia et al., 2019).

Operations-research approaches

OR is the principal decision-making toolkit in green logistics. Garside et al. (2024) reported that 92.58% of the 458 green vehicle routing studies they reviewed proposed a mathematical model, most often MILP. Exact models can give optimal solutions or bounds but become difficult to solve as networks and constraints grow, which helps explain the use of nature-inspired search methods (Zhang et al., 2015). Metaheuristic and hybrid approaches handle larger cases, such as the adaptive large neighbourhood search of Goeke and Schneider (2015), the NSGA-II method of Su and Sukhotu (2025) and the particle-swarm approach of Saicharoen and Pornsing (2026), but they do not normally guarantee a globally optimal solution. Objectives also differ: Dekker et al. (2012) emphasised the cost–emission trade-off, and Ferreira et al. (2020) reviewed multi-objective routing models that optimise economic and environmental goals together.

A third group addresses uncertainty. Das et al. (2020) used fuzzy logic to represent ambiguous parameters, although outcomes depend on membership-function design, while stochastic and robust models handle uncertain demand, travel times and disruption but generally need more data and computing effort. A fourth group applies AI and data-driven methods, which Sood et al. (2025) identify as primary methods in vehicle route optimisation. In the Scopus dataset, the most frequent author keywords include “multi-objective optimization” (65 appearances), “vehicle routing problem” (32), “genetic algorithm” (26) and “particle swarm optimization” (17); these counts reflect research visibility and focus rather than methodological merit. Ye et al. (2022) classify electric-vehicle-routing models by battery constraints, time windows, charging decisions and mixed-fleet design.

Thematic streams

Four themes structure the literature. *Decarbonisation* covers vehicle technology, emission measurement, routing and policy. Road freight is a notable source of greenhouse-gas emissions, so emission-aware routing and fleet choice are central problems (Demir et al., 2014). Emissions depend on speed, traffic, gradient, load and stopping conditions, not distance alone: Xiao and Konak (2016) reported reductions of up to 8% under particular simulated assumptions, and Goeke and Schneider (2015) built speed, gradient and payload into electric-vehicle energy modelling. Adoption remains limited despite policy support (Patella et al., 2021), the environmental benefit of drones is still debated (Chiang et al., 2019), and charging infrastructure and range directly affect route feasibility (Juan et al., 2016). Carbon taxes and cap-and-trade rules appear in routing and cold-chain models (Ma et al., 2020; Su & Sukhotu, 2025; Wang et al., 2017), and Xie et al. (2024) combine renewable energy and electric vehicles in cold-chain planning.

Digitalisation offers clear tools. AI supports prediction and optimisation (Dhamija & Bag, 2020), while the IoT provides live operational data for dynamic decisions (Liu et al., 2019). Aylak (2025) reported reduced costs and emissions in an experimental framework, but such results are model-specific rather than evidence of typical savings. Blockchain, often linked to traceability, appears in 25 abstracts (2.7%) and digital twins in 12 (1.3%), showing limited visible attention under those terms. *Circular systems* broaden the focus from delivery to recovery. Zarbakhshnia et al. (2019) and Govindan and Gholizadeh (2021) model collection, recovery and transport together, although Lozano-Oviedo et al. (2024) point out that early closed-loop work was mostly managerial. Circularity can reduce waste, but collection, sorting and return transport can add emissions, which is why multi-objective models are vital.

Resilience covers the ability to prepare for, respond to and recover from disturbance. Abbasi et al. (2023) designed a green closed-loop network for COVID-19 conditions, and Abbasi et al. (2025) added backup suppliers and special disposal arrangements. Such measures can increase cost, duplication and transport emissions, so resilience and sustainability do not automatically strengthen each other, which Abdelaziz and Munawaroh (2026) describe as a disintegration. Among the 258 abstracts that mention “routing”, 20 (7.8%) mention reverse logistics, closed-loop systems or the circular economy, compared with 108 of 932 records (11.6%) overall. This suggests that circularity is less visible in routing-focused research, although the comparison rests on term occurrence, not manual coding.

Critical evaluation

The literature is abundant in optimisation models but offers limited evidence on external validity, implementation and sustained operational outcomes. Of the 932 records, 330 (35.4%) mention simulation, benchmark, numerical or synthetic testing, 235 (25.2%) mention a case study, real-world setting or empirical context, and 91 (9.8%) mention both. These figures show how studies describe validation, not its quality, but they suggest that many models rely on constructed or adapted benchmark data (Xiao & Konak, 2016; Su & Sukhotu, 2025). Stronger evidence would combine real travel-time, fuel-use, charging and demand data with scenario testing, sensitivity analysis and, where possible, post-implementation evaluation. Uncertainty is receiving more attention, with 213 abstracts (22.9%) mentioning uncertain, probabilistic or robust modelling, yet the distance between model sophistication and adoption remains substantial (Patella et al., 2021). Hydrogen appears in 53 abstracts (5.7%), although low counts may reflect other indexing terms (Konovalov & Adams, 2026; Rose & Neumann, 2020). Overall, decarbonisation and digitalisation are the most visible streams, resilience and circularity remain fragmented, and the main flaw is the gap between modelling sophistication and demonstrated operational implementation.

3. RESEARCH OBJECTIVE

The main objective of this study is to examine the development and current direction of research on green logistics optimization. This is achieved through the following specific objectives:

1. To identify the growth and publication trends in green logistics optimization research.
2. To examine the major themes and sub-themes associated with green logistics optimization.
3. To identify the most influential authors, journals, institutions and countries contributing to this field.
4. To understand the major theories, optimisation methods and technologies used in green logistics studies.
5. To identify research gaps and suggest directions for future research.

4. RESEARCH METHODOLOGY

Systematic literature review

The study adopts a Systematic Literature Review (SLR), a structured method for collecting, evaluating and synthesising existing research on a defined topic, to trace how the field has developed, identify dominant themes and locate gaps. Green logistics optimization designs and manages logistics operations to reduce environmental impact while keeping efficiency intact, spanning route and network optimisation, carbon-aware planning, multi-modal freight design, and AI and machine learning to balance cost, service level and emissions. Prior studies include deep reinforcement learning for green supply chain management (Gao, 2026), low-carbon multi-corridor freight networks (Wei et al., 2026), robust multi-modal network design under uncertainty (Aghaei et al., 2026) and AI-driven route optimisation for drone and last-mile

delivery (Qian, 2026). The process is reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which ensures transparency in the identification, screening, eligibility and inclusion of studies (Page et al., 2021).

Article selection and search strategy

The search was conducted in the Scopus database because of its coverage of business, management, engineering and environmental science journals relevant to the topic. The search string “Green Logistics AND Optimization” was run on 12 September 2026, with the timespan set to 2014–2027 to capture the most recent work. The first search produced 1,675 references. The time-span filter excluded 119 references, leaving 1,556; restricting document types to articles and reviews excluded 556, leaving 1,000; the English-language filter removed 74, leaving 926; and the journal/source filter excluded a further 3, giving 923 studies (Figure 1). The records were later re-exported through Bibliometrix on 23 September 2026, and the dataset analysed in this study contains 932 English-language records published between 2014 and 2026. It comprises 880 articles and 52 reviews, both kept because reviews contribute to the field’s conceptual framing, and 239 records (25.6%) contain the phrase “green logistics” in the title, abstract or keywords. Scopus classified 31 records as articles in press, including 23 dated 2026, so counts for the final year should be read with caution.

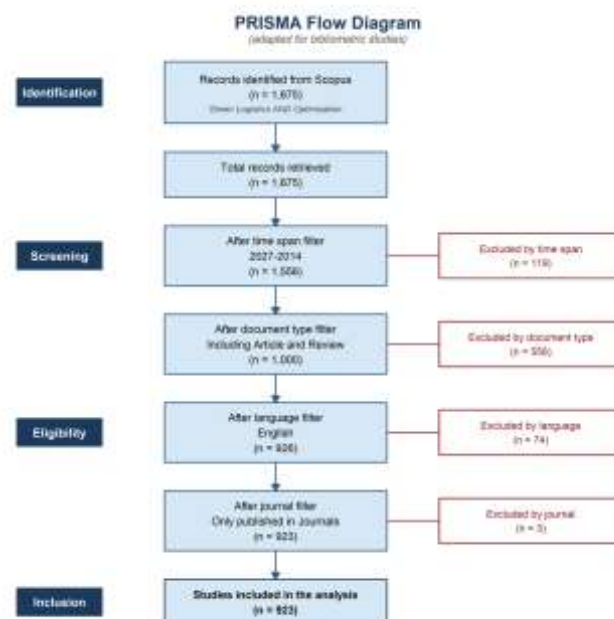


Figure 1. PRISMA flow diagram for the selection of studies on green logistics optimization

Inclusion and exclusion criteria

Studies were included when published between 2014 and 2027, written in English, published as journal articles or review papers, and directly related to green logistics optimization or closely associated concepts. Records were excluded when published outside the selected period, written in another language, or classified as another document type. Studies with no direct connection to green logistics optimization were also excluded during relevance assessment, including records retrieved through keyword overlap, such as studies that use “logistic” in a purely statistical sense (for example, logistic growth modelling). Titles, abstracts and, where necessary, full texts were checked against the research objectives.

Bibliometric analysis

Bibliometric analysis identifies publication patterns, influential contributors, collaboration networks, fre-

quently used keywords and relationships between research themes. Bibliographic information, including citation counts and author keywords, was exported from Scopus. Bibliometrix and Biblioshiny in RStudio, which are built for science mapping (Aria & Cuccurullo, 2017), were used for the descriptive analysis, Microsoft Excel for publication frequencies and trendlines, and VOSviewer for keyword networks, in which node size reflects how often a keyword occurs, link thickness shows how often two keywords appear together, and colours group related terms into clusters. Term counts were generated through automated, case-insensitive searches for specific keywords, such as “simulation”, without manual review of individual results; they reflect the authors’ reporting style rather than methodological quality, and percentages are based on the 932 records with overlapping categories permitted.

Qualitative synthesis

Alongside the bibliometric analysis, a qualitative synthesis grouped the literature into route and network optimisation, green supply chain management, AI and machine learning applications, multi-modal and last-mile logistics, and environmental and regulatory drivers. Examples include carbon-aware path selection, multi-modal corridor design and disruption resilience (Wei et al., 2026; Aghaei et al., 2026); deep reinforcement learning, genetic algorithms and hybrid metaheuristics (Gao, 2026; Hassouna et al., 2026; Qian, 2026); and AI-driven sustainability auditing in digital commerce (Masmali et al., 2026). The methods used in prior studies, such as simulation, real-world case validation, consumer survey data and bibliometric analysis, were also compared, and the findings were brought together to identify gaps and future directions.

5. DATA ANALYSIS AND RESULTS

Overview of the dataset

Bibliometric analysis provides a systematic and repeatable approach to examining the structure and development of a research field, applying quantitative techniques to large volumes of publication data rather than reading every paper individually (Zupic & Čater, 2015). Scopus-indexed publications on green logistics were imported into Biblioshiny. The extracted papers span 2014 to 2026, but 2026 is excluded from the annual trend analysis because indexing for that year was still under way when the data were extracted, and including it would understate actual output.

The dataset consists of 932 documents from 416 distinct sources (journals, conference proceedings and books), contributed by 2,597 authors. Only 61 authors published without a co-author, and each document has close to four co-authors, indicating intensely collaborative research. International co-authorship stands at 29.18%, so roughly three in ten papers involve researchers from more than one country, probably because sustainability in transport and supply chains concerns firms and governments worldwide. The average document age is 2.95 years, suggesting a recent and evolving literature. The 3,122 unique author keywords across 932 documents show a wide vocabulary, hinting that green logistics is a set of interconnected terms around sub-themes such as vehicle routing, carbon emissions and supply chain management. Average citations per document stand at 24.86 and the annual growth rate at 24.33%, suggesting an active, fast-growing and influential area aligned with global carbon-reduction targets.

Annual scientific production: trend analysis

Annual article counts were exported from Biblioshiny to Excel, and trendlines were fitted for 2014 to 2025. The incomplete year 2026 was left out of the fitting because it would pull the trend downward and misrepresent a field that is in fact growing. Annual output rose from 17 articles in 2014 to 188 in 2025, ranging between 12 and 188. As Figure 2 shows, a linear trendline gives $y = 15.61x - 37.577$ with a

coefficient of determination (R^2) of 0.7526 (75.26%). This indicates an overall upward trend, but a straight line assumes a constant rate of increase, which the data do not show: output rose gradually in the early years and then sharply after 2022, curving well above the trendline in 2025–26. The linear model therefore undervalues later output, which explains its lower R^2 .

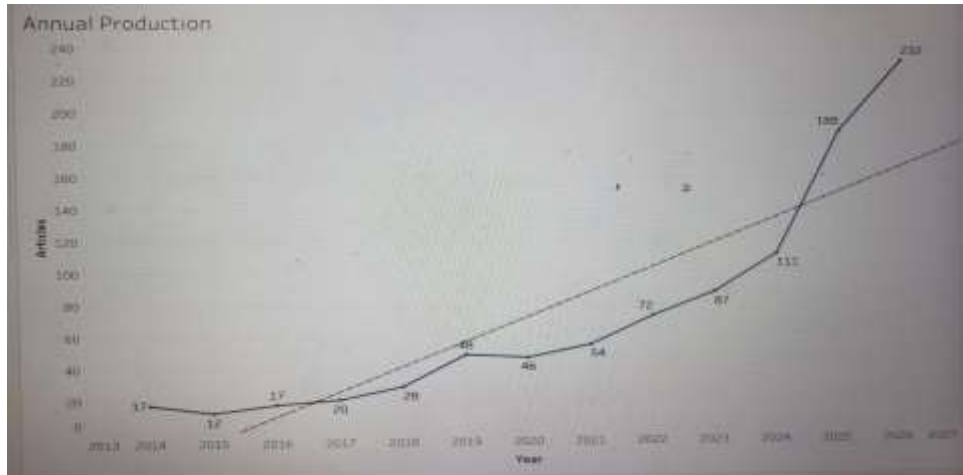


Figure 2. Annual scientific production on green logistics (2014–2026) with fitted linear trendline

Figure 3 shows that publication growth from 2014 to 2018 was gradual and uneven, with a slight decline in 2015 followed by modest increases. From 2019, output increased consistently, and it rose markedly after 2022, from 72 articles in 2022 to 188 in 2025. An exponential trendline gives $y = 9.3286e^{0.2315x}$ with $R^2 = 0.9389$ (93.89%). As Table 2 shows, the R^2 of the exponential model is clearly higher than that of the linear model, and a value closer to 1 indicates a stronger fit. The exponential model therefore represents the growth pattern more closely, implying that growth is compounding, with each year building on the momentum of the previous one. One possible explanation is the increasing attention to environmental regulation and corporate sustainability targets, which may have raised research interest in green logistics and supply chain decarbonisation.

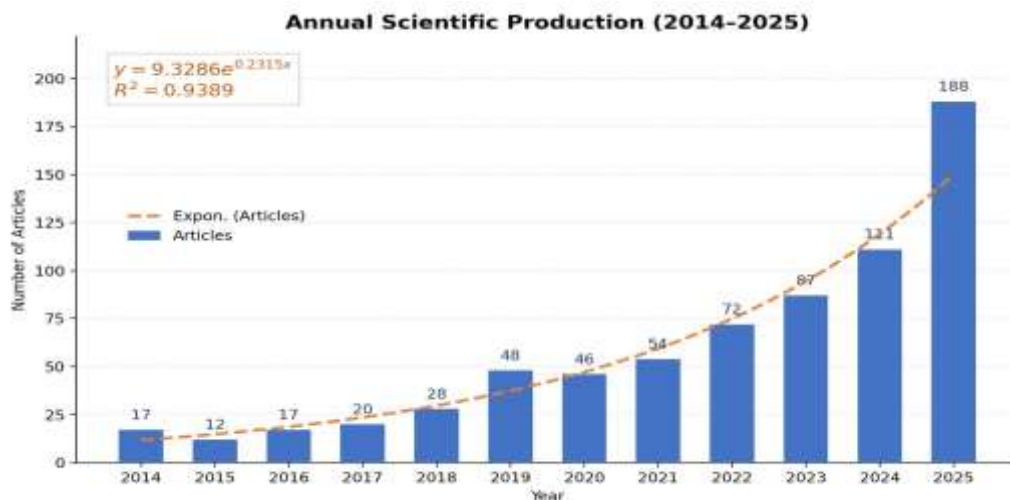


Figure 3. Annual scientific production on green logistics (2014–2025) with fitted exponential trendline

Trendline model	Equation	R ²
Linear	$y = 15.61x - 37.577$	0.7526
Exponential	$y = 9.3286e^{0.2315x}$	0.9389

Table 2. Trendline models fitted to annual scientific production (2014–2025)

Average citations per year

Figure 4 shows the average number of citations received by articles published in each year and reveals clear citation ageing: earlier publications tend to have higher averages. The average peaked at 112.3 citations per article in 2015 and fell sharply to 52.2 by 2017. A mild recovery followed, from 62.5 in 2018 to 68.1 in 2020, which may reflect a second wave of influential publications, before a steep decline from 2021 took the average below 10 citations per article by 2025. This decline should not be regarded as evidence of lower research quality. It more likely reflects the limited time recent articles have had to accumulate citations.

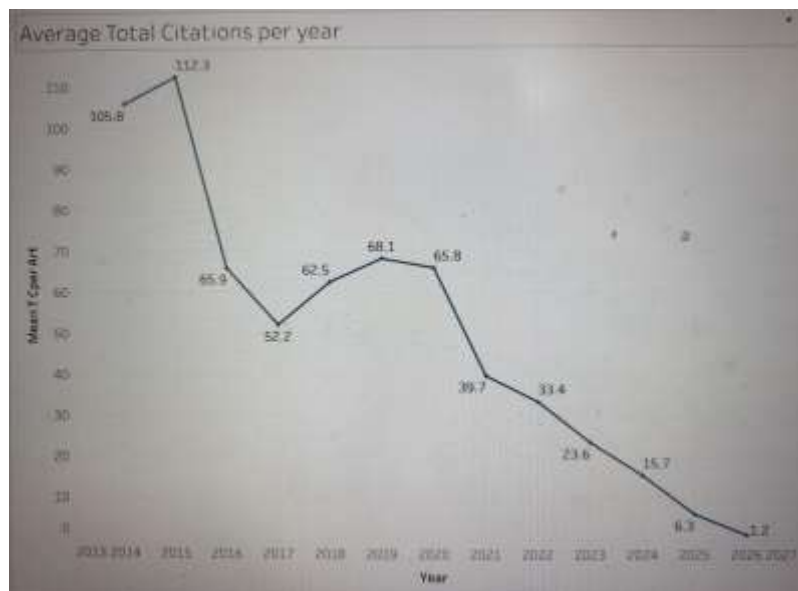


Figure 4. Average total citations per year for green logistics publications

Country scientific production

Figure 5 shows the geographical distribution of research output, with darker shading indicating more publications. China stands out as the largest contributor with 940 documents, followed by India with 149 and the United States with 99. Countries with moderate output include the United Kingdom (64), Iran (33), Australia (32), Italy (20) and Malaysia (14), with Germany, France, Spain and the Netherlands contributing smaller numbers. More than sixty countries have contributed at least one publication, yet output remains heavily concentrated in Asia, particularly China. One possible explanation is China's large-scale manufacturing, e-commerce logistics and urban freight activity.



Figure 5. Country-wise scientific production map

Three-field plot: authors, countries and author keywords

Figure 6 links authors, countries of authors and author keywords. China dominates the middle column and receives the most connections from the author column, followed by India, the USA and the United Kingdom, and many of the most prolific authors, including Li J, Wang J, Zhang C and Li Y, are based in China. The flows from China, India and the USA intersect heavily on “green logistics”, “multi-objective optimization”, “sustainability” and “logistics”, the central themes uniting authors from different countries, while smaller flows reach “reverse logistics”, “green supply chain”, “carbon emission” and “vehicle routing problem”, showing that researchers also explore specialised sub-topics.

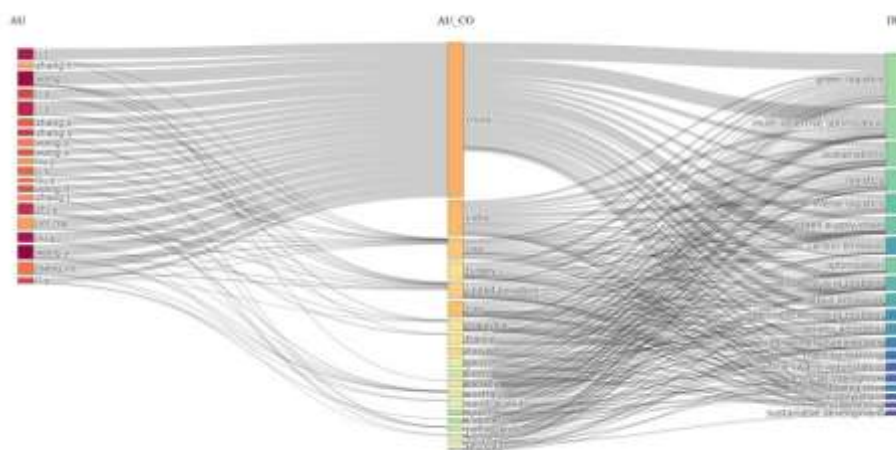
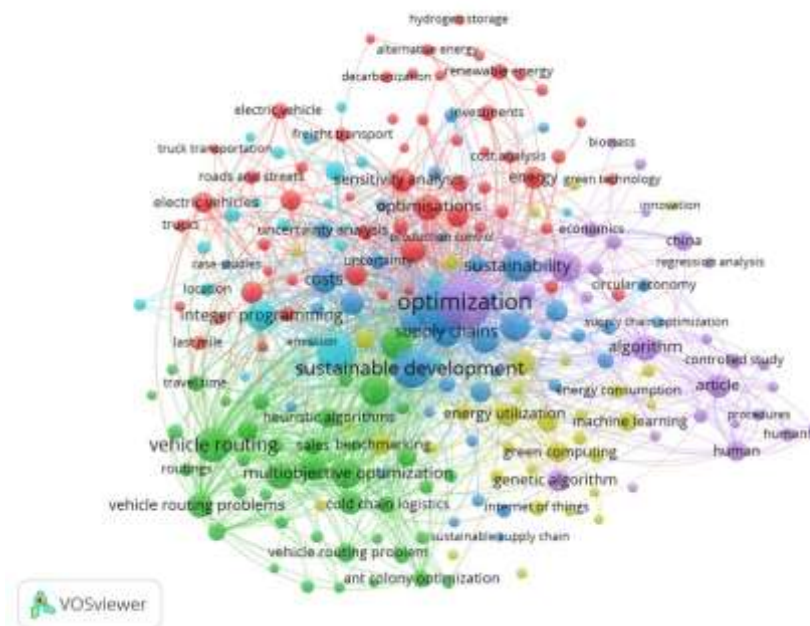


Figure 6. Three-field plot linking authors (AU), country of authors (AU_CO) and author keywords (DE)

Keyword co-occurrence and clustering

The author keywords from the RIS file were imported into VOSviewer for keyword co-occurrence anal-

At the lowest threshold (10), the map is the most detailed and contains five clusters (Figure 7). The red cluster focuses on energy and transport infrastructure (“electric vehicles”, “renewable energy”, “freight transport”, “sensitivity analysis”, “roads and streets”), in line with Al Theeb et al. (2021) on electric vehicle routing and Almouhanna et al. (2020) on location routing with electric vehicles. The blue cluster (“optimization”, “supply chains”, “sustainable development”, “costs”) represents the mathematical and modelling aspect, as in Abdolazimi et al. (2025) on green closed-loop supply chain network optimisation. The green cluster (“vehicle routing”, “multi-objective optimization”, “heuristic algorithms”) covers delivery routes that reduce distance, fuel consumption and emissions together, as in Alamatsaz et al. (2022) on the green capacitated location-routing problem. The yellow cluster (“energy utilization”, “machine learning”, “green computing”, “genetic algorithm”) is a technology-driven stream using computational and AI methods to improve energy efficiency, as in Ahmed et al. (2025). The purple cluster (“sustainability”, “algorithm”, “article”, “human”) is a more general, review-oriented stream, matching the scientometric review of AI-driven green supply chain management by Abbas et al. (2026). Overall, research branches out from a shared optimisation core, with China acting as a major hub.



At the threshold of 25, only the most frequent keywords remain and the map simplifies to four clusters (Figure 8). The red cluster (“multi-objective optimization”, “vehicle routing”, “vehicles”, “particle swarm optimization”, “cost reduction”) is the routing and algorithmic side of the field, consistent with Alfaro et al. (2026) on reducing travel costs and emissions in coin distribution routing and Abibou et al. (2025), who combined deep learning with a branch-and-bound algorithm. The green cluster (“green logistics”, “cold chain logistics”, “integer programming”, “fleet operations”, “optimisations”, “investments”) is concerned with applied, industry-related logistics research. The blue cluster is large and central

(“optimization”, “sustainability”, “supply chain management”, “supply chains”, “green supply chain”, “decision making”, “uncertainty”) and reflects strategic decision-making in green supply chains, as in Ameknassi et al. (2016) on green supply chain design under uncertainty and Abdelaziz and Munawaroh (2026) on sustainable logistics and supply chain resilience. The yellow cluster (“article”, “human”, “algorithm”, “artificial intelligence”, “carbon emission”, “carbon dioxide”) emphasises scientometric analysis and AI-related methods and is strongly connected with China. Taken together, the clusters indicate two main areas: supply chain strategy, and vehicle and routing optimisation.

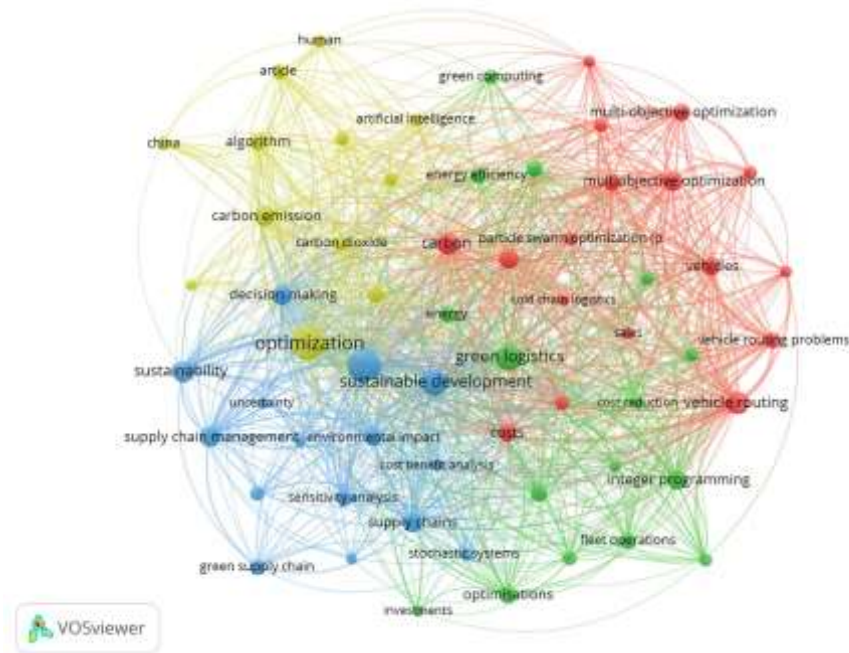


Figure 8. VOSviewer keyword co-occurrence network (minimum occurrences = 25)

At the threshold of 55, only the most dominant keywords remain, reducing the map to three clusters (Figure 9). The blue cluster (“carbon emission”, “emission control”, “carbon”, “algorithm”, “decision making”) shows a strong focus on measuring and reducing carbon emissions, consistent with Cai et al. (2021) on minimising total carbon emissions in connected and automated vehicle routing. The green cluster (“optimization”, “logistics”, “sustainable development”, “sustainability”, “supply chain management”, “supply chains”, “optimisations”) is the largest and most central group, suggesting that supply chain optimisation for sustainability is a major theme. The red cluster contains “multi-objective optimization”, “vehicle routing”, “vehicle routing problems”, “vehicles”, “costs”, “integer programming”, “energy utilization” and “green logistics”. These results are consistent with the lower thresholds: sustainable supply chain management and the optimisation of goods movement through vehicle routing are two closely related areas, linked by carbon and emission themes and by the aim of reducing both costs and environmental impact.



Findings

1. Publication output grew from 17 articles in 2014 to 188 in 2025, an elevenfold increase. The exponential pattern shows that interest in green logistics is rising at more than a linear rate.
2. The literature is highly collaborative and interdisciplinary, with 2,597 authors, 416 sources and 29.18% international co-authorship, bringing together logistics, supply chain management, sustainability, transportation, technology and quantitative decision-making.
3. Optimisation remains the focus of green logistics studies. The VOSviewer analysis shows strong links between sustainability, optimisation, supply chain management, green logistics, vehicle routing, multi-objective optimisation and decision-making, together with a growing presence of AI, machine learning, genetic algorithms, circular economy, reverse logistics, blockchain, Industry 4.0 and carbon emissions. This marks a shift from approaches based on cost and distance towards approaches that consider economic and environmental goals together. Vehicle routing and network optimisation matter especially because transportation decisions directly affect fuel use, emissions, delivery time and cost.
4. Model sophistication does not by itself make solutions ready for large-scale implementation: of the 932 records, 330 refer to simulation or benchmark testing and 235 to a case study or empirical context, but only 91 include both.
5. Research output is geographically concentrated, with China, India and the United States contributing most publications and Asia, particularly China, dominating.

Green logistics optimization should be treated as an interdisciplinary field rather than a purely transportation or environmental one: beyond the mathematical structure of OR, effective research needs knowledge of supply chain management, environmental management, information technology, transportation, economics and sustainability. The academic agenda should shift towards integrated multi-objective models that consider emissions, service quality, resilience, uncertainty, energy consumption,

customer requirements and social aspects together, rather than only cost or emissions. More emphasis is needed on dynamic and uncertain environments, where AI, IoT data, digital twins and predictive analytics can support real-time optimisation, and further work is possible on hydrogen logistics, blockchain, electric fleets and circular supply chains.

Business implications

Companies should not treat green logistics merely as an environmental responsibility or compliance issue. It can be a crucial strategic and operational decision-making mechanism: optimisation methods can identify efficient routes, improve vehicle utilisation, avoid unnecessary transportation, manage inventories, optimise distribution networks and bring environmental costs into operational decisions. However, firms should not invest in optimisation technologies simply because they are technically advanced; given the discrepancy between mathematical solutions and implementation, they must assess compatibility with their infrastructure, human resources, data access, budget and processes. AI, IoT, electric vehicles and circular approaches improve visibility but need investment and workforce capability. A good green logistics strategy therefore weighs environmental performance against cost, service quality, resilience and practicality.

Social implications

More efficient and sustainable logistics can create cleaner cities, less pollution and congestion, healthier communities and a better quality of life, especially where freight and last-mile transportation are heavy. Sustainability should not, however, be considered only from an environmental perspective. Changes in logistics technology can affect communities, employment patterns, skills needs and workers: some manual tasks may be automated and some decisions made using AI, increasing demand for technical and analytical skills. Green logistics should therefore also attend to employee training and adaptation, social welfare and community impacts.

7. FUTURE RESEARCH AGENDA

Publications on the optimisation of green logistics grew from 17 in 2014 to 188 in 2025, but the level of evidence behind the models has not grown in parallel. The gaps identified in the analysis drive the agenda below.

Validation with real-world evidence

Only 91 of the 932 records (9.8%) include both a case study or empirical setting and simulation or benchmark testing, and previous reviews confirm that models are usually tested in idealised environments (Dekker et al., 2012; Demir et al., 2014). Future work could use real fleet, warehouse and delivery data, run operational pilots with logistics companies and publish post-implementation results. Comparing predicted with achieved emission savings would demonstrate robustness.

Integrated multi-objective and uncertainty modelling

Multi-objective optimisation is the largest part of the keyword network, but most models optimise only cost and emissions (Ferreira et al., 2020; Xie et al., 2024). Later work can include service level, resilience, energy use and social outcomes in the same formulation. Only 22.9% of records use uncertain, probabilistic or robust modelling, although demand, travel time and disruptions seldom follow assumed patterns, so stochastic and robust approaches deserve more attention, supported by scalable heuristic and metaheuristic methods (Garside et al., 2024).

Reverse logistics and circular economy design

Closed-loop supply chains and the circular economy are less developed in the keyword network than veh-

icle routing. Researchers could build network models that consider forward and reverse flows together (Zarbakhshnia et al., 2019) and link them to circular business models and performance measurement (Kazancoglu et al., 2018; Lopes de Sousa Jabbour et al., 2019). Quantitative models for green inventory management also remain limited (Becerra et al., 2021).

Alternative-fuel fleets and last-mile delivery

Classical routing models do not deal with the range, charging and battery limitations of electric and alternative-fuel vehicles (Juan et al., 2016). These constraints need explicit modelling, especially in urban last-mile delivery, where green vehicles are growing most rapidly (Patella et al., 2021). Other avenues, including hydrogen infrastructure and the decarbonisation of road freight, have also been explored (Meyer, 2020).

Digital technologies and real-time decisions

Keywords such as artificial intelligence, machine learning, IoT, digital twins and blockchain are emerging but are not necessarily associated with “optimization model”. Future research could feed IoT data streams and digital twins into dynamic rerouting, use predictive analytics to forecast demand and emissions, and use blockchain to track emissions, while also studying the cost of these tools and organisational capacity to implement them.

Geographical concentration

International co-authorship stands at only 29.18%, and the evidence remains concentrated in a limited number of research-intensive countries. Contributions from developing countries would be valuable, and regional comparative work could show how far models are transferable and how they should be adapted to differences in infrastructure, regulation and energy mix.

Methodological extensions

Because this review relied on a single database and authors’ terminology, studies using terms such as sustainable logistics may have been missed. Adding databases beyond Scopus, co-citation analysis (Zupic & Čater, 2015) and other science-mapping tools (Aria & Cuccurullo, 2017) would be appropriate, and findings could then be compared with earlier bibliometric studies of green and sustainable supply chains (Fahimnia et al., 2015; Islam et al., 2021; Wang et al., 2023).

8. CONCLUSION AND LIMITATIONS

This study shows that green logistics optimization is a large and rapidly growing application of OR to one of the most significant problems of modern supply chains. The analysis of 932 records reveals strong academic activity and identifies optimisation, sustainability, supply chain management, vehicle routing and multi-objective decision-making as key areas, while new technologies and ideas such as Industry 4.0, AI and machine learning, the circular economy, reverse logistics and blockchain are pushing the frontiers of the field. The key take-away is that more complex mathematical models will not be enough: models must become more realistic, flexible, measurable and implementable. Researchers need to link optimisation with reality, businesses need to account for the environment in economic and operational decisions, and decision-makers need to consider the social impact of technological change. Green logistics is thus more than an attempt to green transport; it is a transformation of logistics systems in design, operation and evaluation, and the continuing transition of OR towards sustainability and new technologies can lead to logistics systems that are green, efficient, resilient, economically viable and socially responsible.

Several limitations should be acknowledged. First, the large number of publications, authors, keywords and sources and the overlap between research areas made data consistency and dataset management challenging, and the study relied on a single database, Elsevier's Scopus. Second, terminological variation across green logistics, sustainable logistics, green supply chain management, reverse logistics and green transportation makes the field boundaries hard to define precisely. Third, data for 2026 were incomplete at extraction, so 2026 was excluded from the annual trend analysis, which shows the difficulty of analysing a growing field whose latest publications may not yet be indexed. Fourth, keyword co-occurrence does not necessarily imply research depth or quality, and different words with the same meaning can place studies on one topic under different keywords, so the networks were interpreted carefully rather than as a direct measure of importance. Finally, many studies rely on mathematical models, benchmark datasets, simulations or hypothetical scenarios that may not capture changes in demand, traffic congestion, charging availability, supply interruptions or regulation, which underlines the need for further work linking theory and logistics practice.

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