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*Systematic Review*

# Transforming Humanitarian Supply Chains Through Green Practices: A Systematic Review

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**Abstract**

*Background*: This systematic review explores the integration of green practices into humanitarian supply chains to mitigate environmental impacts and contribute to global decarbonization efforts. *Methods*: This review focused on peer-reviewed articles published between 2011 and 2024 that addressed the environmental dimension of humanitarian logistics. Studies were included if they examined environmental practices within humanitarian supply chains and excluded if they lacked focus on environmental impact or logistics. A comprehensive search of the Scopus database in April 2024 yielded 291 records, of which 51 studies met the inclusion criteria. A thematic synthesis was conducted; due to the qualitative nature of the data, no formal risk-of-bias assessment was conducted. *Results*: The analysis revealed increasing adoption of environmentally focused practices, such as emissions monitoring, waste reduction, and resource-efficient transportation. Key barriers included operational complexity, inadequate digital infrastructure, and the absence of standardized environmental frameworks. The review identified digital innovation, inter-organizational collaboration, and integrated environmental performance metrics as promising pathways for improvement. Despite growing awareness, significant gaps remain in the standardization and measurement of environmental performance across humanitarian supply chains. *Conclusions*: The findings highlight the need for further research and coordinated efforts to develop consistent, scalable green practices in the humanitarian context.

**Keywords:** green supply chain; sustainability; humanitarian supply chain; humanitarian logistics; systematic review

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## 1. Introduction

Humanitarian logistics have become increasingly critical as the frequency and intensity of global crises have risen, driven by climate change, conflicts, and natural disasters. In its Global Humanitarian Overview, the UN Office for the Coordination of Humanitarian Affairs (OCHA) projected that nearly 300 million people worldwide would require humanitarian assistance and protection in 2024 because of escalating conflicts, climate-related disasters, and other factors [1]. This surge in need underscores the importance of delivering essential goods and services, such as food, medical supplies, and shelter, to vulnerable communities. The core goal of humanitarian logistics is to save lives and alleviate suffering as quickly and effectively as possible in high-pressure environments. As humanitarian operations have expanded to meet increasing demand, there has been growing recognition

of the environmental impact associated with these efforts, including high-carbon emissions, waste generation, and the depletion of natural resources in vulnerable regions [2].

Recent years have seen a shift toward incorporating green practices into humanitarian logistics. This has been driven by the urgent need to balance rapid response with environmental sustainability, especially as climate change makes certain regions vulnerable to recurring crises. However, adopting green practices in humanitarian contexts presents a unique challenge: how can the environmental footprint of supply chains be reduced without compromising their primary objective of delivering life-saving aid? For humanitarian logistics, environmental goals must not come at the expense of speed, accessibility, or efficacy in delivering aid.

Despite the rising awareness, research on green humanitarian supply chains (GHSCs) remains limited. Most studies on humanitarian supply chains have concentrated on operational efficiency and responsiveness; few have explored how environmental considerations can be systematically incorporated without undermining crisis-response capabilities. This review addresses this gap by synthesizing existing research on green practices in humanitarian logistics. We examined the current state of the literature, the role of green logistics practices, the main barriers to GHSCs, and future directions in the field to offer insights into how these can evolve to meet the demands of humanitarian aid and contribute to long-term environmental resilience.

GHSCs also support many of the sustainable development goals, such as Goal 2 (zero hunger) and Goal 3 (good health and well-being), by ensuring sustainable food distribution and access to essential medical supplies while reducing waste. Goal 6 (clean water and sanitation) and Goal 7 (affordable and clean energy) are supported by promoting responsible water use and integrating renewable energy into logistics. GHSCs also promote Goal 9 (industry, innovation, and infrastructure) and Goal 11 (sustainable cities and communities) by fostering green technologies, climate-resilient infrastructure, and minimizing the environmental impact of humanitarian aid.

The remainder of this article is structured as follows. In Section 2, we position this study in the literature, highlighting its relevance and contribution to the field. We outline the research methodology in Section 3, articulating the steps taken to execute a systematic literature review. Our descriptive analysis of the selected studies is presented in Section 4. Section 5 presents our discussion and analysis of the findings to answer the research questions. Finally, in Section 6, we conclude by discussing the study's limitations and suggesting avenues for future research.

## 2. Positioning

Green supply chain management has been receiving increasing amounts of attention in the supply chain literature, but it remains underexplored in the humanitarian field. Existing reviews have examined related areas, including Industry 4.0 technologies [3,4], theories and research methods [5], research avenues suggested by theory [6], as well as specific topics like freight logistics [7]. However, these studies have not addressed the unique challenges of implementing sustainable and green practices in humanitarian supply chains, particularly the need to integrate environmental considerations and the urgent social objectives of crisis response.

Given the increasing pressure to reduce the environmental impact of humanitarian operations while delivering life-saving aid, addressing this gap is essential. This review takes up the challenge by systematically examining green practices within humanitarian supply chains, highlighting strategies for carbon reduction, minimizing environmental impact, and improving resource efficiency. This comprehensive synthesis of current advancements, challenges, and pathways for further development offers insights to guide the sector toward

practices that support humanitarian objectives and reduce environmental harm. This focus on GHSCs is crucial for building supply chain models that are effective in crisis response and aligned with broader goals of sustainability and environmental responsibility.

## 3. Methodology

A systematic review involves a comprehensive, structured, and methodical assessment of the scientific literature. Its primary aim is to minimize bias in responding to a defined research question by identifying and synthesizing existing findings on a specific topic [8]. Academically, this approach enhances methodological rigor. For practitioners and managers, it aids in building a credible knowledge base by integrating the insights of multiple studies [9]. We followed this methodology, beginning with formulating research questions to define the scope of the review. In this stage, the main keywords, search strings, and other characteristics related to the review protocol were also established. In the second stage, we selected studies for inclusion via six steps, as depicted in Figure 1: (1) identifying pertinent articles, (2) filtering studies by document type and language, (3) excluding articles based on title, keywords, and abstract reviews, (4) using a snowball process to find additional relevant articles, (5) conducting a quality assessment to identify pertinent articles, and (6) creating a data-extraction sheet for the final sample that captures the review's findings and results. The methodology is compliant with PRISMA guidelines [10].

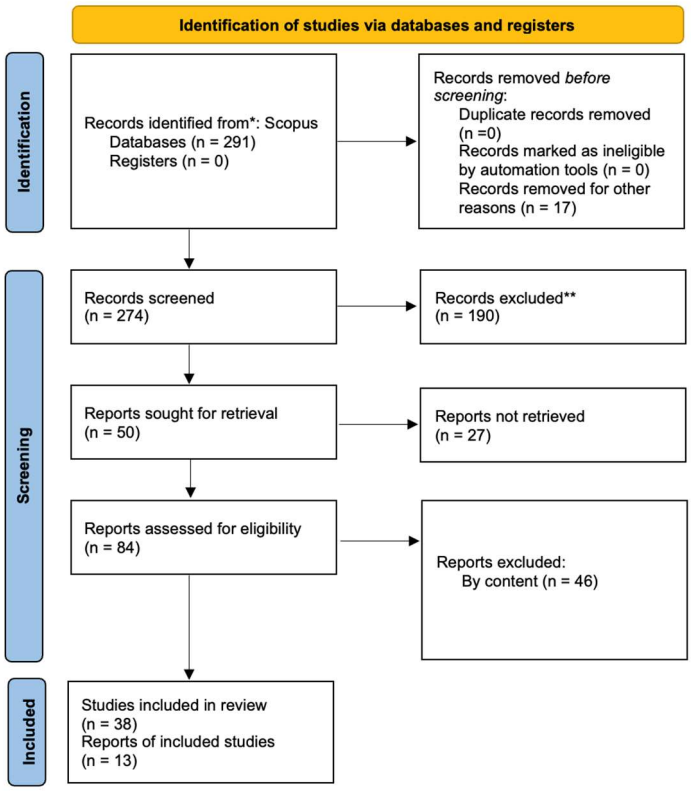



**Figure 1.** Study selection process to obtain the documents to be reviewed.

### *3.1. First Stage: Research Methodology*

We consider both quantitative and qualitative studies. We did not include a filter in terms of timeframe, but following the study selection stage, we retained only articles published between 2011 and 2024. Although humanitarian logistics has been a subject of study for many years, it is only since 2011 that the integration of green and sustainability concepts in humanitarian supply chains has attracted significant attention [11,12]. The

studies published since have emphasized environmental concerns, decarbonization efforts, and the minimization of environmental impacts in humanitarian operations.

Keywords in the first group are related to environmental sustainability—(i) carbon, (ii) environment, (iii) green, (iv) sustainab *—and those in the second group are related to humanitarian supply chains—(v) humanitar * and (vi) supply chain; the asterisk serves as a truncation tool that effectively broadens the search results, ensuring that relevant documents with different forms of the same lexical root are not excluded. The following search query was used to perform this review: TITLE-ABS-KEY ("carbon" OR "green" OR "environment" OR "sustainab *") AND ("humanitar *" AND supply chain). A summary of the review methodology is presented in Table 1.

**Table 1.** Process followed for the systematic literature review.

| | |
|---|---|
| Research Questions | 1. What is the current state of the literature on green humanitarian supply chains?<br>2. What is the role of green logistics practices in reducing environmental impacts and minimizing carbon emissions in disaster relief?<br>3. What barriers hinder effective green humanitarian supply chain practices?<br>4. What are the potential avenues for future research in this field? |
| Stings | ("carbon" OR "green" OR "environment" OR "sustainab *") AND ("humanitar *" AND supply chain) |
| Language | English |
| Timeframe | No filter |
| Type of reference | Journal articles (review articles for positioning and research articles) and peer-reviewed conference papers |
| Database | Scopus (broad and high-quality indexing of peer-reviewed journals across disciplines relevant to our topic) |

### *3.2. Second Stage: Study Selection*

The method's second stage, study selection, consisted of six steps, as illustrated in Figure 1. The objective at this stage was to develop a data extraction sheet capturing key information from each article. The initial search yielded 291 articles. We excluded specific types of publications (such as editorials, reviews, and documents not in English), leaving 274 documents.

We then conducted a detailed evaluation of the remaining articles. Specifically, we assessed the titles and abstracts of the articles to assess their relevance to the review. This step led to the exclusion of 84 papers. Next, we applied a snowball sampling technique to gather additional insights pertinent to the research questions from various sources; we retrieved 13 supplementary articles as a result.

In step 5, both authors independently screened the full texts to ensure alignment with the review's focus on humanitarian supply chains, logistics, and environmental sustainability. Articles were included if they addressed green practices, sustainability, or environmental factors within humanitarian contexts. Studies unrelated to humanitarian operations or lacking relevance to environmental concerns were excluded. Any disagreements were resolved through discussion. This process resulted in a final selection of 51 articles. Having finalized the sample, the last step was to complete the data extraction sheet for all articles. This helped us summarize the key findings and insights from the literature.

## 4. Descriptive Analysis

The evolution of academic interest in GHSCs from 2011 to 2024 is depicted in Figure 2. In the initial period (2011–2018), there was very little research on this topic, suggesting a limited focus on environmental practices in humanitarian logistics. In 2019, there was a

notable increase (seven articles), suggesting that the topic attracted significant attention, possibly influenced by global climate initiatives. However, research output dropped in 2020, possibly due to the disruptions caused by the COVID-19 pandemic, which affected research outputs worldwide. Research interest in GHSCs increased after 2020, with a significant peak in 2022 (nine articles), suggesting a renewed focus on sustainable practices as the humanitarian sector embraced green initiatives. Importantly, at the time of writing (in late 2024), it is possible that additional articles will be published in the calendar year, potentially impacting this trend. The pattern identified highlights the growing recognition of GHSCs as a vital area for aligning humanitarian efforts with sustainability goals.

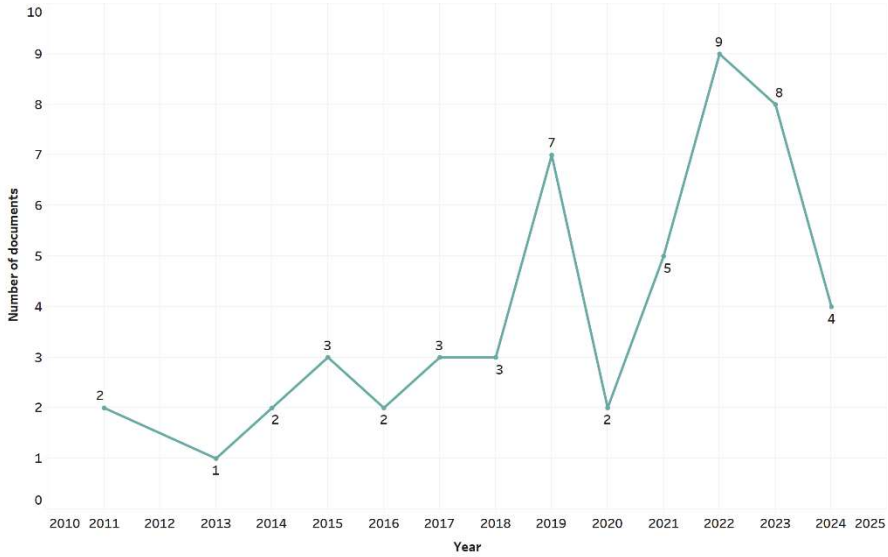



**Figure 2.** Number of related publications in the field per year.

The journals that published the highest number of articles identified in the search were the following: *Annals of Operations Research* (nine articles), *Journal of Humanitarian Logistics and Supply Chain Management* (four articles), *Sustainability (Switzerland)* (four articles), and *Journal of Cleaner Production* (two articles). These journals have in common their interest in topics related to sustainable practices, green logistics, and environmentally responsible supply chains. Each journal explores these topics in its own way. *Annals of Operations Research* occasionally includes sustainability-focused studies relevant to methodologies employed in operations research, while *The Journal of Humanitarian Logistics and Supply Chain Management* address topics like disaster relief, emergency response logistics, and efficient resource distribution, with a focus on green and sustainable practices. *Sustainability (Switzerland)* and *Journal of Cleaner Production* both cover the broad areas of sustainable development and green practices, with *Sustainability* focusing on interdisciplinary research and the *Journal of Cleaner Production* emphasizing cleaner production techniques and reducing environmental impacts across supply chains.

Figure 3 presents the publication counts of key authors in the field, making it easy to identify prolific contributors and their collaborative networks. Authors sharing a color in the chart are co-authors; a gray bar indicates co-authorship with researchers not in the primary list. For instance, Comes, Lauras, and Salvado co-authored three papers, represented by yellow, blue, and pink bars.

Many of the articles reviewed incorporated case studies simulating real-life disasters and crises to reflect the nature and purpose of humanitarian logistics and test theory in realistic settings. Among the 51 papers reviewed, we identified 30 case studies across 19 countries, covering about 59% of the total sample. Figure 4 shows a world map color-coded according to the number of case studies per country and the type of crisis addressed.

China and Haiti are the locations studied most frequently, and natural disasters (particularly earthquakes) have been studied more than other types of crises. Importantly, the global impact of the COVID-19 pandemic has meant that it has been extensively researched.

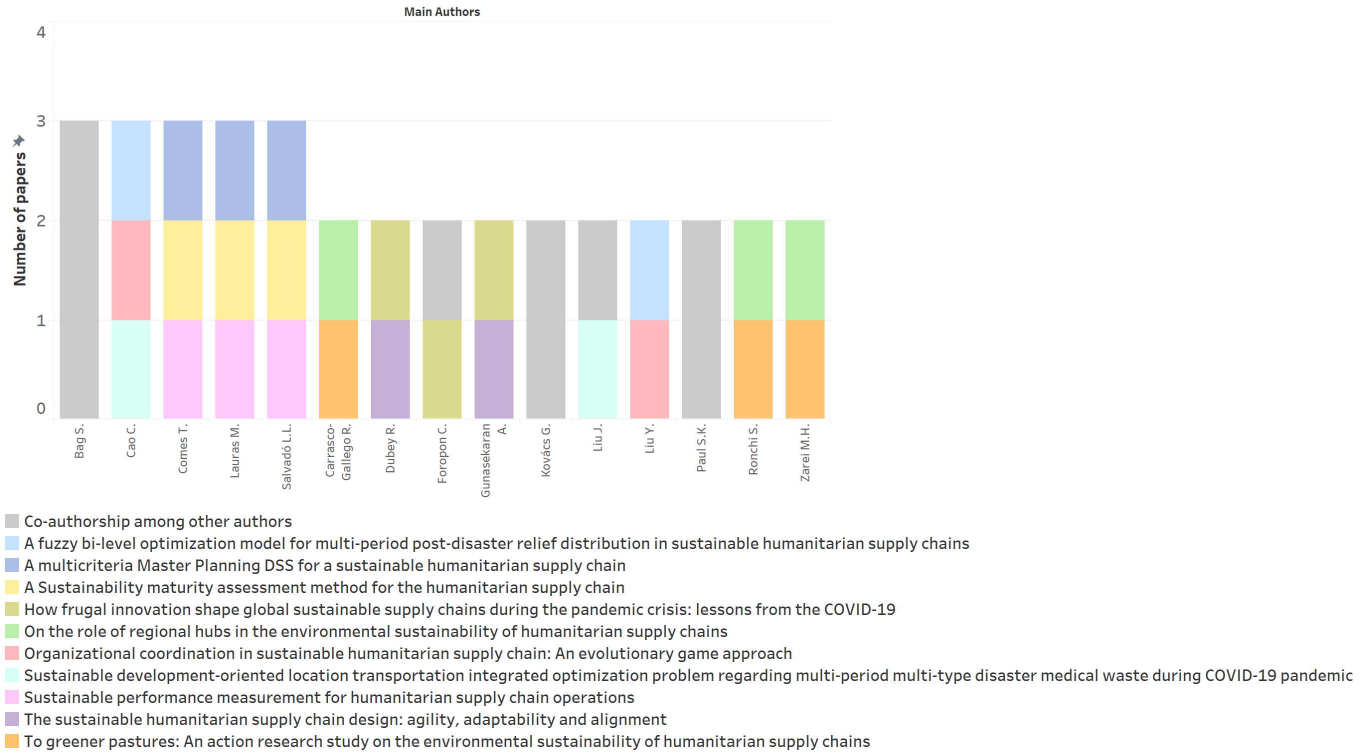



**Figure 3.** The main authors of GHSCs and their collaboration networks.

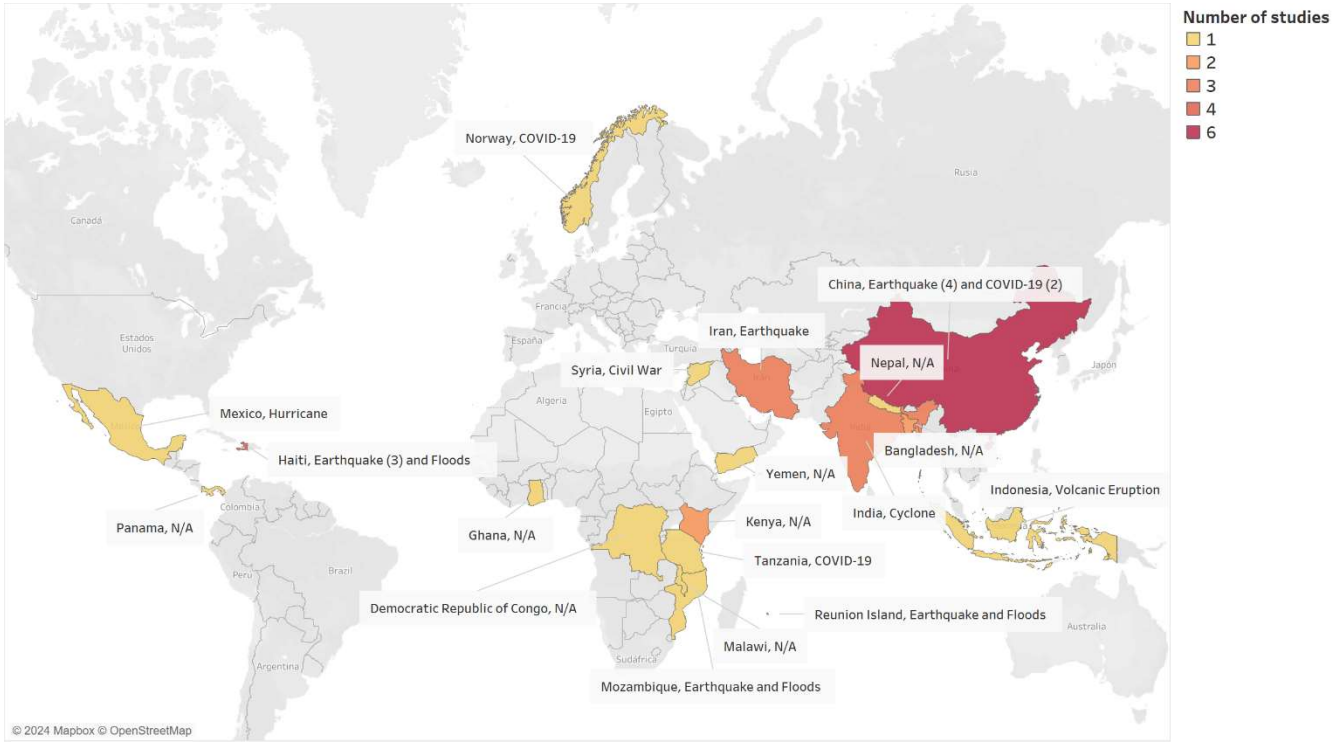



**Figure 4.** Number of case studies by country and type of natural or man-made disaster.

Finally, we conducted a VOSViewer 1.6. 20 analysis to identify the main topic clusters based on the most frequently cited keywords in titles and abstracts, as illustrated in

Figure 5. Three primary clusters emerged from this analysis. Cluster 1 (carbon footprint, carbon reduction, environmental sustainability, green supply chain, humanitarian aid, life cycle assessment, decision-making, facility location, disaster management) highlights the importance of green initiatives in decision-making processes in humanitarian supply chains. The analysis also indicates that sustainability, environmental impact, and reducing the carbon emissions of humanitarian logistics have only recently attracted attention. Nevertheless, as shown graphically, these topics remain underexplored, presenting a valuable opportunity for further research.

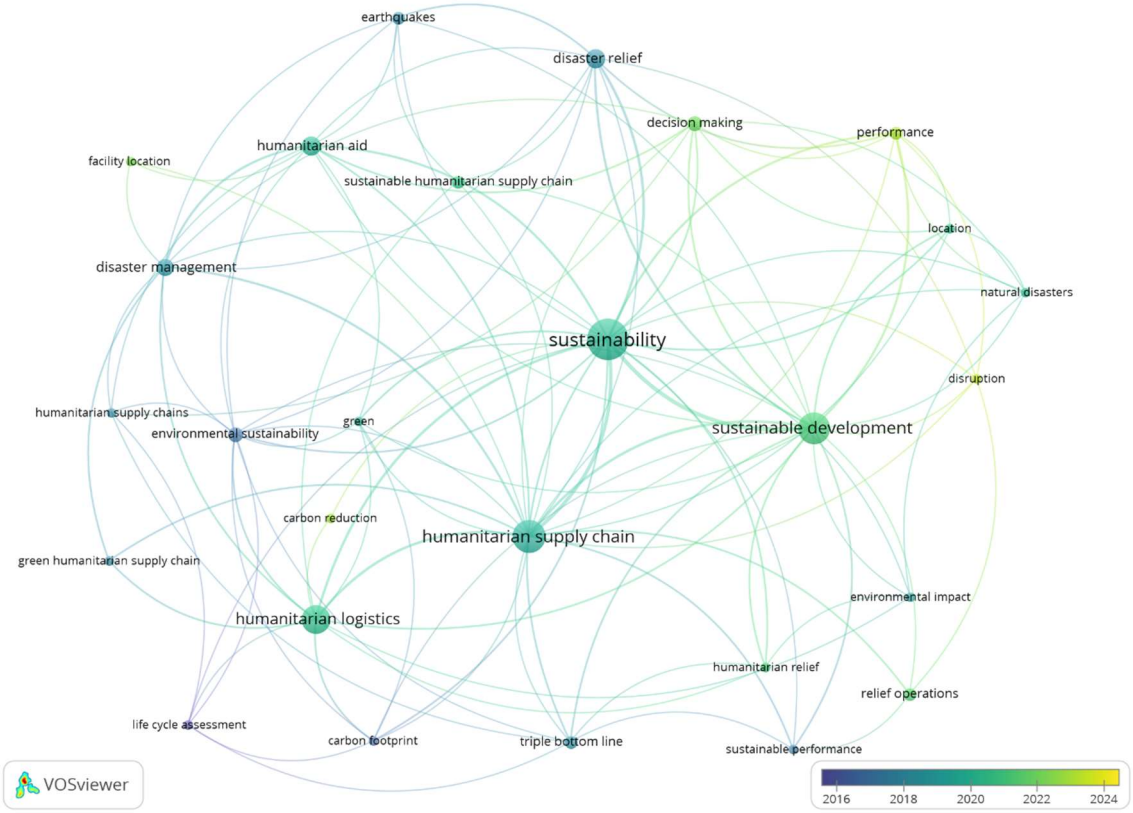



**Figure 5.** Network and clusters of co-occurrence keywords for GHSCs generated by VOSviewer.

## 5. Discussion

This literature review has addressed the four research questions set out below.

1. What is the current state of the literature on green humanitarian supply chains?

The literature on GHSCs reveals a complex and rapidly evolving field. Diverse perspectives are offered regarding how best to integrate environmental goals into disaster relief operations. Key themes include developing sustainable models, adapting green logistics practices from the commercial sector, and designing decision-making tools that balance achieving environmental objectives with the need for speed and efficiency in humanitarian operations.

A primary challenge identified in the literature is tailoring green objectives to be aligned with the urgency of humanitarian missions. This issue can be tackled through systematic modeling. Network analysis was used to offer a broad overview of GHSCs, pinpointing where existing theoretical models fail to build in the adaptability/flexibility required when delivering aid in high-pressure disaster relief scenarios [3]. The authors of [13] built on this, developing multi-objective frameworks that prioritize logistical efficiency and environmental sustainability; the study underscored the value of adaptable

decision-making tools that can quickly adjust to changing demands. Both studies suggest that, despite theoretical advancements, flexibility and real-world applicability remain underdeveloped in many existing GHSC models.

Specific environmental metrics have been integrated into emergency response models to address this need for adaptable and sustainable frameworks. Scholars have proposed bilevel frameworks that combine emissions tracking with resource allocation strategies, placing carbon emission goals at the forefront of GHSC considerations [14]. Others have focused on eco-friendly packaging and materials to further reduce waste, supporting sustainability at each step of the supply chain [15]. Together, these authors have highlighted the potential for incorporating green practices throughout GHSC operations. However, they also acknowledge that the urgency of humanitarian response often results in supply chain actors deprioritizing environmental considerations. These studies reflect a shared recognition that effective, practical models are needed to incorporate sustainability into the various strategic and operational aspects of disaster relief.

Evaluating the effectiveness of green logistics practices in these frameworks relies on specific indicators. Sustainability parameters are frequently overlooked in assessments of the performance of humanitarian logistics networks [16]. Noting that other performance metrics often dominate, the authors call on decision-makers to prioritize environmental impact assessments to improve processes and anticipate future challenges. However, some studies [13,14] have emphasized carbon emissions per kilometer traveled and total fuel consumption as the primary metrics for measuring the environmental impact of transportation in disaster relief. The authors of [15] added indicators like waste generation from packaging materials and the efficiency of resource use, underscoring the importance of minimizing material waste and maximizing resource use. Others have advocated for emissions per shipment and fuel efficiency as essential performance measures, allowing organizations to set environmental targets and track progress over time. The authors of [17–19] argue for the inventory turnover rate and energy consumption during storage as critical indicators of the environmental footprint of warehousing. Together, these indicators establish a multi-objective framework that allows researchers and practitioners to monitor sustainability goals without sacrificing the efficiency that is vital in disaster relief.

The literature has also explored how commercial green logistics practices might inform GHSCs, with [11,20] offering contrasting perspectives. The authors of [20] suggested that practices such as reverse logistics and closed-loop supply chains, which are widely adopted in the commercial sector, can reduce environmental impact in humanitarian operations by encouraging waste reduction and recycling. In contrast, The authors of [11] argued that the unpredictable nature of humanitarian logistics requires that these commercial practices be carefully adapted. Despite this difference, these studies reflect agreement that modified commercial practices can support sustainability in GHSCs if adjusted to ensure flexibility and responsiveness in crisis settings.

Decision-making and performance measurement remain focal areas in the GHSC literature. The authors of [13] argued that decision support systems (DSSs) should be tailored to GHSCs, pointing out that existing DSS frameworks generally prioritize speed and cost, often overlooking environmental impact. The authors of [17] echoed this concern, advocating for the inclusion of environmental performance metrics, such as emissions per shipment and fuel efficiency, as essential components of GHSC evaluation. This comparison reveals a consensus on the importance of DSS tools, although the field remains divided on how best to integrate environmental metrics without compromising on speed.

The studies reviewed employ diverse methods to address the unique challenges of GHSCs. Their conceptual frameworks offer a theoretical basis for response modeling, while insights from key stakeholders on logistical needs and limitations are obtained through

interviews and surveys. Quantitative methods, such as multi-objective models and exact approaches [21], allow precise analysis of resource allocation and optimized decision-making. The qualitative and mixed-methods studies in our sample [22,23] capture the nuances of implementing green practices, with multi-criteria decision-making used to prioritize factors like cost, response speed, and environmental impact. Together, these methodologies advance practical and theoretical knowledge regarding sustainable humanitarian logistics. Table 2 highlights the main methodological approaches used in the literature.

Digitalization has been essential to advancing green practices. Reference [19] argued that digital tools improve forecasting accuracy, reducing resource overuse and unnecessary shipments. The use of digital tracking to monitor emissions, enabling data-driven insights that support sustainable logistics decisions, has also been highlighted as essential [18]. The shared focus on digitalization reflects a broader trend in the GHSC literature in support of human operations using technology to harmonize environmental objectives with logistical demands in real time.

The growing reliance on these indicators across GHSC frameworks suggests an emerging consensus on the metrics needed for the effective evaluation of sustainable practices. The GHSC literature have adopted metrics such as emissions, carbon footprint, fuel or energy consumption, waste reduction, and resource efficiency. These studies have thus established standardized criteria to guide the assessment and design of green humanitarian logistics models. These studies reveal a strong commitment to embedding environmental performance in the strategic and operational aspects of disaster relief, advancing comprehensive, sustainable supply chain solutions that meet the demands of humanitarian response.

**Table 2.** Main methodological approaches in GHSCs.

| Reference | Case Study | Mixed Approaches | Multi-Criteria Decision-Making | Quantitative | | | | Qualitative | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mathematical Approaches | Simulation | Statistical Analysis | Life Cycle Assessment | Conceptual | Interviews | Survey | Focused Groups | Action Research | Field Research |
| [22] | √ | | | √ | √ | | | | √ | | | | |
| [21] | √ | | | √ | | | | | | | | | |
| [23] | √ | √ | | | | √ | | | √ | √ | | | |
| [16] | | √ | √ | | | | | | | | | | |
| [24] | √ | √ | | √ | √ | | | | | | | | |
| [25] | √ | | | √ | √ | | | | | | | | |
| [26] | √ | | √ | | | | | | | | | | |
| [27] | | | | | √ | | | | | | | | |
| [28] | √ | | | | | | | √ | √ | | | | |
| [29] | | | | √ | | √ | | | | | | | |
| [18] | | | | | | | | | | | | | |
| [14] | √ | | | √ | | | | | | | | | |
| [15] | √ | | | √ | √ | | | | | | | | |
| [30] | √ | | | √ | √ | | | | | | | | |
| [31] | | √ | √ | | | | | √ | | √ | | | |
| [32] | | | √ | | | | | | | | | | |
| [33] | √ | | | √ | | | | | | | | | |
| [17] | | √ | √ | | | | | | | | | | |
| [34] | √ | | | | | | | | √ | | | | |
| [35] | | √ | √ | | | | | √ | | | | | |
| [36] | | | √ | | | | | | | | | | |
| [37] | √ | | | √ | | | | | | | | | |
| [38] | √ | | | √ | | | | | | | | | |
| [39] | | | √ | | | | | | √ | | | | |
| [39] | √ | | | | √ | | | | | | | | |
| [40] | √ | | √ | | | | | | | | | | |
| [41] | | √ | √ | | | | | | | | | | |
| [42] | √ | | | √ | | | | | | | | | |
| [13] | | | √ | √ | | | | | | | | | |
| [43] | | | | √ | | | | | | | | | |
| [44] | √ | | | √ | √ | | | | | | | | |
| [45] | | | | | | | | √ | | | | √ | |
| [46] | | | | √ | √ | | | | | | | | |
| [47] | √ | √ | √ | | | | | | | | | | |
| [48] | √ | √ | | | | | | √ | | | √ | | |
| [49] | | | | | | | | √ | | | | | √ |
| [50] | | | | √ | | | | | | | | | |
| [51] | | √ | | | | √ | | | | √ | | | |
| [52] | √ | | | | | | √ | | √ | | | | |

**Table 2.** *Cont.*

| Reference | Case Study | Mixed Approaches | Multi-Criteria Decision-Making | Quantitative | | | | Qualitative | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mathematical Approaches | Simulation | Statistical Analysis | Life Cycle Assessment | Conceptual | Interviews | Survey | Focused Groups | Action Research | Field Research |
| [53] | √ | | | | | | | √ | | | | | √ |
| [54] | | | | √ | | | | | | | | | |
| [55] | | | | | | √ | | √ | | √ | | | |
| [20] | | | | √ | | | | | | | | | |
| [56] | √ | | | √ | | | | | | | | | |
| [57] | √ | | | | | | √ | | | | | | |
| [58] | √ | | | | | | | √ | | | | | |
| [59] | | √ | | | | | | | | | | | |
| [60] | √ | | | | | | | | √ | | | | √ |
| [61] | | | | | | | | √ | | | | | |
| [12] | | | | | | | | √ | √ | | | | |
| [11] | | | | | | | | √ | | | | | |

2. What role do green logistics practices play in reducing environmental impacts and minimizing carbon emissions in disaster relief?

Adopting green logistics practices in disaster relief is an important way to reduce the environmental impacts of these efforts and to minimize their carbon emissions. Several studies have highlighted complementary approaches to achieving these goals.

Optimizing transportation and the location of warehouses or shelters has been suggested as a means to reduce emissions. The authors of [25] have argued that selecting appropriate transportation modes and optimizing routes is essential to green logistics strategies in the context of disaster relief. The findings of this study show the value of fuel-efficient transport options and strategic routing to ensure that rapid responses are environmentally sustainable. Similarly, reference [24] demonstrated that factors such as fleet size, the use of multiple transportation modes, and logistics network configuration can significantly impact service levels, transportation costs, and carbon emissions in last-mile humanitarian supply chains; these factors can contribute to more efficient relief efforts. Reference [18] focused on sustainable location-allocation practices, emphasizing strategically placing warehouses to reduce travel distances and fuel consumption. This approach minimizes the overall carbon footprint of transportation, which is a core component of green logistics in humanitarian contexts.

Focusing on supply chain configurations and the integration of sustainable practices in inventory management, reference [15] proposed a model that incorporates eco-friendly materials and consolidated shipments. This allows disaster relief organizations to lower their waste and resource consumption while maintaining logistical efficiency. Similarly, reference [30] noted the need for lean and green inventory management practices that support rapid response and environmental conservation. By centralizing essential supplies and implementing sustainable packaging, these practices contribute to reduced emissions and waste, which are particularly valuable in disaster scenarios where resources are often scarce.

The authors of [17] emphasized the role of performance measurement in green logistics, suggesting that disaster relief organizations should use performance metrics such as emissions per shipment, fuel efficiency, and waste reduction as benchmarks for evaluating the environmental impact of their logistics. By tracking these metrics, organizations can continuously refine their practices to reduce their environmental footprint, improve processes, and anticipate future challenges. The focus on measurable outcomes allows a structured approach to green logistics that contrasts with the more flexible models suggested by [18,25], who emphasized strategic planning over specific metrics.

Various studies have suggested that adapting successful green commercial practices could offer a structured logistics framework to reduce the environmental impact of disaster relief. The authors of [11] have argued that the commercial sector's experience with green logistics practices, such as eco-friendly transportation and renewable energy-powered

warehousing, could benefit humanitarian organizations. Reference [12] extended this comparison, noting that the adoption of green logistics in disaster relief is often hindered by the need for urgency; however, they argued that practices like route optimization and emission-tracking technologies could help close this gap.

The authors of [19,39] identified digitalization as a critical enabler of green logistics, focusing on how real-time tracking and data analytics can improve resource allocation and reduce waste in disaster relief. Reference [19] emphasized that digital tools can enhance forecast accuracy and reduce excess inventory and unnecessary trips. The authors of [39] noted the potential of data analytics for tracking emissions in real time and making it possible to make immediate adjustments that minimize the environmental impact of logistics. These findings align with the performance-driven approach discussed by [17], in which data-driven decision-making underpins sustainable logistics.

Finally, engaging local communities and organizations can significantly enhance the effectiveness of green logistics in humanitarian supply chains. Collaboration among stakeholders (such as NGOs, governments, and local communities) promotes more sustainable sourcing and distribution methods, ultimately reducing emissions. Reference [42] stressed the importance of such collaboration in advancing sustainability in humanitarian logistics, and reference [41] pointed out that establishing strong, cooperative relationships with supply chain partners is essential for improving the speed and quality of crisis response. Strategies like joint procurement, integrated online platforms for inter-organizational transportation and fleet management, shared warehousing, and consolidation of shipments for last-mile delivery can significantly reduce the risk that aid supplies will expire, lower fuel consumption, and minimize emissions during transportation [48]. These practices enhance operational efficiency and contribute to a more sustainable and environmentally responsible humanitarian supply chain.

In conclusion, integrating green logistics practices is essential for reducing the environmental impacts of disaster relief. These practices of transportation optimization, inventory management, performance measurement, and digitalization together offer robust ways to minimize carbon emissions in disaster response. This literature review has highlighted the diverse approaches taken to achieve a more environmentally sustainable humanitarian logistics framework. These range from strategic location planning to digital tracking.

3. What are the barriers to effective green humanitarian supply chain practices?

The present review has revealed several barriers to effective implementation of green practices in humanitarian supply chains, with studies focusing on various specific challenges. One critical barrier is the complexity of integrating sustainable practices into the existing humanitarian supply chain framework. The authors of [22] discussed this concern, pointing out that the intricate logistics of these supply chains—often under urgent, high-stakes conditions—make it difficult to implement green practices without compromising speed and efficacy. This complexity is compounded by the lack of standardized methodologies and configurational tools that might accommodate green adaptation without disrupting essential processes.

Another significant barrier, highlighted by [21], is that there are no comprehensive and multidimensional models that simultaneously account for environmental impacts and operational and social objectives in humanitarian settings. The authors argued that most existing models focus on cost and speed, and environmental concerns are treated as secondary. The lack of a robust modeling framework means that green initiatives often lack the structural support necessary for successful implementation.

The authors of [25] identified various transportation-related logistical challenges as a primary obstacle to green practices. Humanitarian supply chains often rely on multimodal transportation to reach diverse and remote areas. These methods are typically

selected based on availability and urgency rather than environmental efficiency. As a result, transportation in humanitarian contexts often has a high carbon footprint because rapid deployment is prioritized over reducing the environmental impact. The authors emphasized that unless logistics and environmental impact are integrated into one approach, implementing green practices will continue to be a challenge in such settings.

Further compounding these logistical issues, as reference [28] pointed out, is the difficulty of accurately calculating and monitoring emissions within a humanitarian supply chain. Unlike commercial supply chains, with consistent routes and schedules, humanitarian supply chains are characterized by unpredictable routes and variable demands. Reference [28] suggested that the lack of accurate emissions data limits the ability of organizations to set and monitor environmental targets, further impeding efforts to pursue green practices.

Another clear obstacle is the limited use of digital technologies in humanitarian logistics that can support green initiatives [18]. The authors argued that digital tools, such as real-time tracking and data analysis, could facilitate efficient resource management and reduce waste and emissions. However, digitalization in humanitarian logistics is seldom properly funded and is underutilized, and there are a range of inefficiencies that could be addressed with appropriate technology.

Lastly, the authors of [12] have pointed out that there are few frameworks for stakeholder collaboration, negatively impacting the scaling of green practices. Coordination of humanitarian supply chain actors, including NGOs, governments, and private companies, is often ad hoc and without long-term environmental planning. This fragmentation leads to inconsistent green practices across supply chain partners who each prioritize their individual operational goals over collective environmental targets.

In summary, the implementation of green practices in humanitarian supply chains is hindered by multiple interrelated barriers, including the complexity of integrating these practices into urgent supply operations, the lack of comprehensive models, logistical challenges in transportation, difficulties with emissions monitoring, underutilization of digital technologies, and fragmented stakeholder collaboration. Addressing these barriers requires a coordinated approach that ensures environmental factors are considered in the structural and operational dimensions of humanitarian supply chains.

4. What are the potential avenues for future research in this field?

The literature reflects several aligned and complementary research priorities for minimizing environmental impact in GHSC operations. It is important to develop advanced models to manage environmental factors in GHSCs. The authors of [22] suggested approaches like fuzzy-set qualitative comparative analysis to support environmentally resilient supply chains. This careful approach to environmental sustainability produces adaptable frameworks that account for fluctuating environmental pressures. Complementing this approach, reference [21] advocated for multidimensional models that incorporate environmental factors alongside other operational considerations, positioning GHSCs to address ecological constraints more holistically.

In a more technical vein, the authors of [18,28] focus on reducing emissions and leveraging digitalization to improve environmental efficiency within GHSCs. Reference [28] quantified the emissions generated by digitalized transportation networks, suggesting that detailed emissions tracking is essential to reducing the carbon footprint of humanitarian supply chains. The authors of [18] extended this focus to the digitalization of inventory management, proposing that advanced forecasting and resource-tracking tools can lead to more efficient, lower-impact supply chain practices. Researchers are exhibiting growing interest in the incorporation technologies that will facilitate the effective implementation of green practices across the phases of humanitarian logistics (preparedness, response,

recovery, and mitigation). Technologies such as artificial intelligence [16], blockchain [31], big data analytics [32,37,40], IoT, and machine learning [29] are seen as critical to supporting the environmental goals of humanitarian logistics. Together, these authors have emphasized that digital tools can drive sustainable practices by enabling precise environmental performance metrics and improving resource planning.

Sustainable supply chain models need to be validated in real-world, environmentally challenging scenarios, particularly disaster-prone regions. This validation is crucial for comparing and testing the generalizability of results across disaster types, countries, or continents to gain a deeper understanding of the impact of GHSCs [19,24,34,55]. Reference [13] tested these models across diverse conditions and argued that their environmental efficacy and adaptability can be assessed by researchers. Similarly, reference [45] recommended incorporating environmental resilience factors into GHSC frameworks to improve the capacity of supply chains to withstand ecological disruptions, such as extreme weather events. Both perspectives support field-based validation to ensure the effectiveness of green models in the face of the actual environmental stressors in humanitarian contexts.

The authors of [31,45] suggested that future studies should take into account the other phases of humanitarian logistics, such as preparedness, response, recovery, and mitigation, to appreciate the big-picture impact of GHSCs. Concerning reverse logistics strategies, references [20,38] highlighted the potential of this strategy and sustainable inventory practices to reduce the environmental impact of GHSCs. These authors have suggested that by prioritizing the reuse, recycling, and optimized inventory management of resources, humanitarian supply chains can significantly lower waste and emissions, aligning with the principles of the circular economy. The authors of [20] argued that reverse logistics can provide a structured approach to resource recovery, which is crucial in regions where environmental sensitivity and resource scarcity intersect.

Finally, concepts such as resilience and agility, as well as lean principles, are important for the development of GHSCs. With resilience, humanitarian operations can quickly recover from disruptions, such as natural disasters or resource shortages, allowing efficient victim assistance. Agility allows rapid adaptation to changing demands and unexpected conditions, ensuring that resources are distributed effectively. Lean principles focus attention on reducing waste and maximizing resource utilization, supporting environmental sustainability goals by minimizing carbon emissions and reducing excess materials. Paying attention to these elements can strengthen GHSCs by enhancing their efficiency, responsiveness, and environmental responsibility, ultimately leading to more effective and sustainable disaster relief efforts [26,30].

## 6. Conclusions

This review has emphasized the importance of integrating green practices into humanitarian supply chains to achieve sustainability goals and effective disaster relief operations. The findings indicate that GHSCs are in an early stage of development, and they have significant potential to reduce carbon emissions, optimize resource use, and enhance resilience to environmental impacts. However, there are considerable obstacles to implementing GHSCs, such as logistical complexities, limited stakeholder collaboration, and low levels of digitalization. Coordinated strategies are needed across the sector to improve the effectiveness of GHSCs.

Currently, strategies and frameworks are often proposed for specific crises or country contexts, with tailored testing and validation. The studies reviewed here have offered valuable insights into the field, but their potential applicability across countries or to similar crises is limited. Future research should focus on developing adaptable and sustainable models that can be validated across diverse real-world settings.

Finally, standardized environmental metrics should be adopted to assess the impact of GHSCs, and technological tools can support agile and data-driven logistics solutions. By promoting resilience, agility, and lean principles, GHSCs can evolve to become more sustainable systems that align humanitarian responses and environmental goals. This approach enhances the crisis response capabilities of humanitarian actors and addresses essential global challenges.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| GHSC | Green Humanitarian Supply Chain. |
| DSS | Decision Support System. |
| UN | United Nations. |
| OCHA | Office for the Coordination of Humanitarian Affairs. |

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