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Green supply chain management in healthcare: A comprehensive bibliometric analysis of trends and future directions

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ABSTRACT

Green supply chain management (GSCM) has gained increasing attention as a strategy to minimize the environmental impact of healthcare supply chains. The healthcare sector is a significant contributor to global greenhouse gas emissions and medical waste, making sustainability a critical concern. Despite growing research on GSCM, a comprehensive understanding of its research trends and emerging areas in healthcare remains limited. This study aims to conduct a bibliometric analysis of GSCM research in the healthcare sector, identifying key trends, influential authors, research collaborations, and emerging themes to provide insights into its development and future directions. A bibliometric analysis was conducted using the Scopus database, covering publications from 2002 to 2024. Data cleaning was performed using OpenRefine, and visualization was carried out with VOSviewer and R Studio. The analysis included annual publication trends, geographical distribution, journal and author impact, keyword mapping, and research clusters. A total of 158 publications were identified, showing an average annual growth of 5.76%. The most active contributing countries were India, Iran, China, the United States, and the United Kingdom. Keyword analysis revealed four main research clusters, including sustainability and supply chain management, environmental impact and decision-making, healthcare applications of GSCM, and blockchain and digital innovations in healthcare supply chains. The findings highlight the growing importance of GSCM in the healthcare sector and the increasing role of digital innovations. Future research should focus on technology-driven solutions, policy frameworks, and optimization strategies to enhance sustainability in healthcare supply chains. These insights are valuable for researchers, practitioners, and policymakers in developing more efficient and environmentally responsible healthcare supply chains.

Keywords: green supply chain management, healthcare, bibliometric analysis, sustainability.

INTRODUCTION

In an increasingly complex era of globalization, environmental sustainability awareness has become a major focus in various sectors, such as the healthcare industry (Luiz et al., 2024). One approach that has received increasing attention in the sustainability movement is green supply

chain management (GSCM). GSCM is the practice of integrating environmental considerations into supply chain management, covering the entire production cycle of a commodity, including design, raw material sourcing, production processes, and distribution of the final product to consumers (Srivastava, 2007a; Zhu et al., 2008).

The healthcare sector, one of the world's largest industries, has a significant environmental impact. According to data from the World Health Organization (WHO), the healthcare sector is responsible for producing approximately 4.4% of global greenhouse gas emissions (WHO, 2021). In addition, the healthcare industry also generates a large amount of medical waste that has the potential to be harmful to the environment and threatens public health (Husaini et al., 2023; Thakur & Ramesh, 2015). Therefore, the implementation of GSCM in the healthcare sector is becoming increasingly crucial for reducing environmental impacts, improving operational efficiency, and ensuring long-term sustainability (Feng et al., 2024).

GSCM is an approach to supply chain management that aims to decrease environmental impacts through environmentally friendly practices at every stage of the supply chain (Khaleeli et al., 2021; Srivastava, 2007b). GSCM emerged in response to the need to integrate environmentally friendly practices into supply chain management (Benzidia et al., 2021a; Gupta, 2022). The concept covers all aspects from product design to final product disposal by considering the environmental impact at each stage (Herrmann et al., 2021; Hidayat et al., 2022).

Research on GSCM in the healthcare sector has grown rapidly in recent years, covering a wide range of complex and multidimensional aspects. Some of the areas that have been explored include medical waste reduction, green product procurement (Oruezabala & Rico, 2012; Sahoo et al., 2024), hospital logistics optimization (Islam & Habib, 2023), green technology implementation in healthcare (Khor et al., 2016; S. M. Lee & Lee, 2022), and green supply chain implementation in various industries (Chiou et al., 2011; Jiang et al., 2018).

Despite increasing interest in this field, there are still gaps in the comprehensive understanding of the GSCM research landscape in the healthcare sector. Some of these challenges include the complexity of healthcare supply chains (de Vries & Huijsman, 2011), the need for the standardization of GSCM practices (Garg et al., 2016; Kumar et al., 2021), and the integration of technology in green supply chain management (Dubey et al., 2017). In addition, differences in geographical and regulatory contexts between countries affect the implementation of GSCM in the healthcare sector (Susanty et al., 2019).

Bibliometric analysis has proven to be an effective method for identifying trends, patterns, and gaps in the scientific literature (Donthu et al., 2021; van Eck & Waltman, 2014). Using this technique, we can gain a better understanding of the evolution of GSCM research in the healthcare sector, including key topics, research collaborations, and future research directions. Some bibliometric studies have been conducted in the context of GSCM in general (Fahimnia et al., 2015; Maditati et al., 2018), but no comprehensive analysis has focused specifically on the health sector.

Given the importance of GSCM in achieving sustainable development goals (SDGs) in the health sector (Velazquez et al., 2015), a deeper understanding of current research trends and developments is needed. Bibliometric analysis can help identify knowledge gaps, collaboration opportunities and potential areas for future research (Zupic & Čater, 2015). This will provide valuable insights for researchers, practitioners and policy makers in developing effective and sustainable GSCM strategies in the healthcare sector.

This article aims to provide a bibliometric analysis of the literature on GSCM in healthcare, focusing on trends in research developed in recent years. The results of this analysis are expected to significantly contribute to the collective understanding of GSCM in the healthcare sector and serve as a foundation for future research and innovation. As such, this study will not only enrich the academic literature but also potentially provide practical implications for efforts to improve sustainability in the global health system.

METHODS

Data collection

Bibliographic data were collected from two leading scientific databases, namely, the Scopus website from Elsevier. The choice of using these databases was based on the coverage and quality of the publications. The search terms used in the search field were "green supply chain management", "sustainable supply chain", "healthcare", "hospital", and "medical".

Data cleaning

The data obtained from Scopus are then checked using the OpenRefine application. OpenRefine combines author keywords and index keywords that have different writings but have the same meaning, such as Covid 19 with Covid-19, combining plural and compound words such as supply chain with supply chain. The use of OpenRefine is intended to avoid bias in the number of occurrences of data in keyword analysis.

Visualization data sharing

Data that have been cleaned using Open Refine are then grouped using the VosViewer application (Van Eck & Waltman, 2010) and R Studio (Aria & Cuccurullo, 2017). Some aspects analyzed include a) annual publication trends, b) geographical distribution of research, c) the most productive journals, and d) the most impactful authors and institutions. For data visualization, VoS Viewer was used for keyword analysis visualization, while for publication distribution maps by country and affiliation graphs, Tableau software was used.

RESULTS AND DISCUSSION

General information

The general information on publications in Figure 1 related to GSCM in the health sector shows publications from 2002 until 2024, with 158 documents with a significant average annual growth of 15.76%. There are 462 authors involved in this topic, 12 of them are single authors. The diversity of document types consists of 106 journal articles and 18 conference papers, 13 book chapters, 13 conference reviews, and 8 other document types, illustrating the various distributions of article types published by researchers on GSCM in the health sector.

Total publications per year

The analysis of annual publication trends (Figure 2) reveals an increase in publications over these two decades. From 1 publication in 2002, this number increased dramatically to 38 publications in 2023, and in 2024, there were 25 publications. Given the current trend, this number is predicted to continue to increase until the end of the year. The growth of publications began to look significant in 2014, with 7 publications, and continued to increase consistently in the following years. The increase in publications 56 clearly occurred in 2019, with 16 publications, followed by a steady increase until it reached its peak in 2023.

This trend reflects the increasing urgency and relevance of this topic in an international context that increasingly emphasizes sustainability and efficiency in health systems. Despite minor fluctuations in some years, the overall trend shows significant growth. This indicates that GSCM in the healthcare sector has become an increasingly important research focus, driven by factors such as increasingly stringent environmental regulations (Zhao et al., 2023), increasing consumer awareness (Jhawar & Jain, 2016), and the need for operational efficiency in the global health system (Mbau et al., 2023).

Publications by country

The analysis of the distribution of articles by geographic region in Figure 3 shows that research on GSCM in the healthcare sector is widespread globally, with 55 countries contributing to this topic. The country with the highest number of publications is India, with a total of

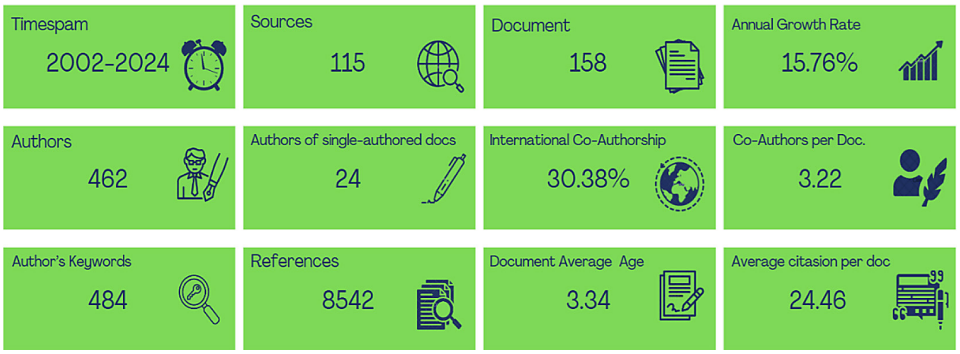

Figure 1. Overview of GSCM in healthcare

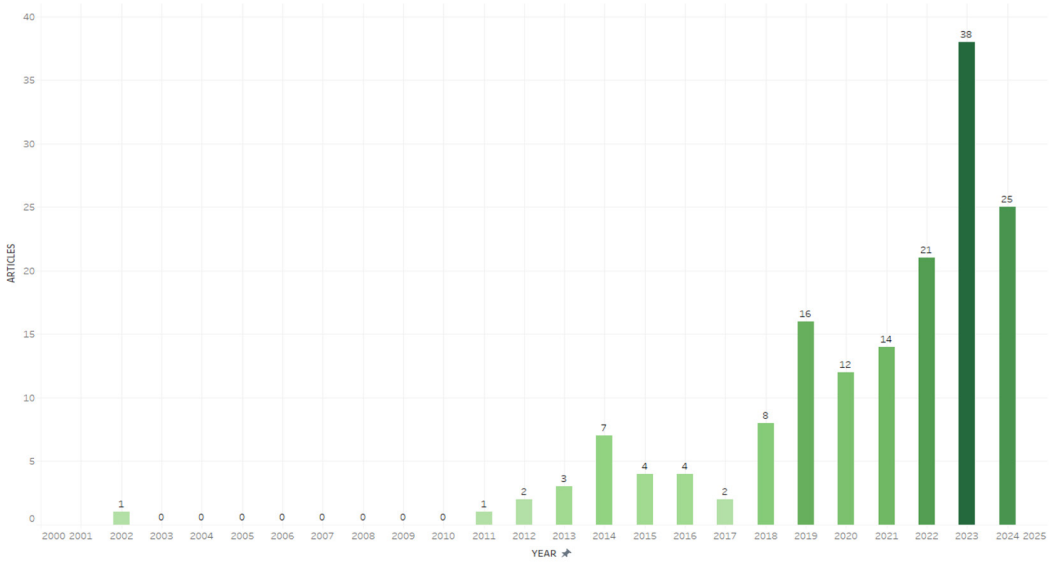

Figure 2. Annual publications trend from 2002 to 2024 for the topic of green supply chain management in the healthcare sector

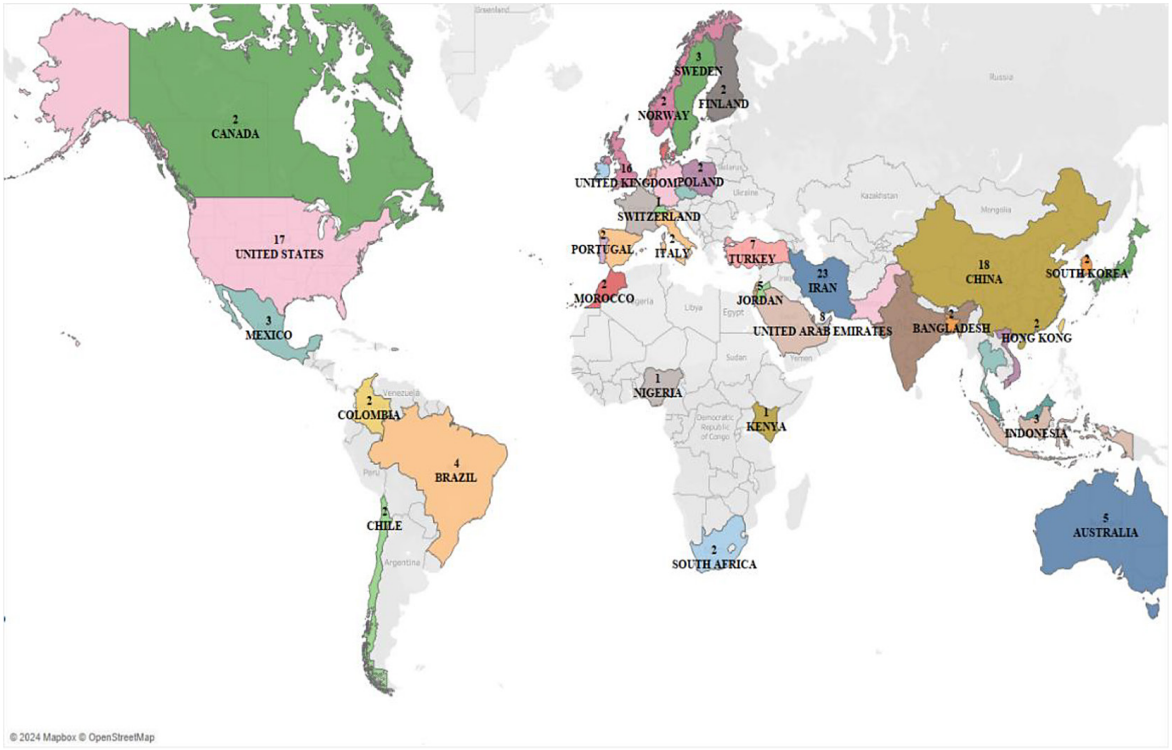

Figure 3. Global publication distribution on GSCM in healthcare

25 documents, followed by Iran (23), China (18), the United States (17), and the United Kingdom (16). India's dominance in terms of the number of publications reflects the country's focus on innovation in healthcare supply chain management and its commitment to sustainable practices. The strong presence of Asian countries such as Iran, China, and Malaysia among the top five contributors indicates a shift in research focus to this region. This may be driven by rapid economic growth, increased investment in health systems (van Gool et al., 2021), and a growing awareness of environmental issues in developing countries (Filippini & Srinivasan, 2022). Moreover, significant contributions from the United States and the United Kingdom suggest that developed countries remain important centers for research in this area.

Most influential journals based on the number of articles and number of citations

The journal analysis in Table 1 shows that research on green supply chain management in the healthcare sector is spread across various publication outlets, reflecting the interdisciplinary nature of this topic. There are 88 journals that have articles on the topic of green supply chain management in the healthcare sector. In the analysis of the highest-published journals, "Sustainability" leads with 8 publications and an h-index of 5, followed by the "Journal of Cleaner Production" with 6 publications and an h-index of 6. These two journals, which focus on sustainability and cleaner production issues, are becoming major platforms for the dissemination of research in this area. "Environmental Science and Pollution Research" and "Technological Forecasting and Social Change" also emerged as important journals, with 5 and 4 publications, respectively. The presence of these journals shows that green supply chain management research in the healthcare sector not only focuses on operational aspects but also considers broader environmental and socio-technological implications.

Analysis of the most influential journals on the basis of citations reveals that the International Journal of Production Economics is an important contributor, with a total of 665 citations from 2 documents. This journal shows the high relevance and influence of publications in the field of GSCM in the health sector. The journal Technological Forecasting and Social Change has a strong impact, with 399 citations from 4 documents. This shows that while some journals may not have the highest number of publications, the quality and relevance of the articles contribute significantly.

The analysis of the most influential authors in Table 2 reveals interesting patterns in the field of GSCM in healthcare. When sorted by the number of citations, Kouhizadeh Mahtab, Saberi Sara, and Sarkis Joseph stand out, with 665 citations each from a single article published in 2021. The extremely high number of citations for recent publications suggests that their work has made a significant impact in a short period of time. Authors such as Bentahar Omar and Benzidia Smail, with two publications each and a significant citation count of 293, balance total publications and total citations. The articles published by Omar Bentahar and Smail Benzidia show a balance of quantity with the quality of the published articles.

Most influential authors based on the number of articles and number of citations

The authors with the highest publication counts represent diverse research groups. Dangayach G.S., Gupta Sumit, Meena M.L., and Vishwakarma Amit have 3 publications each published in 2023, with a total of 35 citations. The clustering of recent publications from the same group of authors suggests a focused research program or a collaborative effort between authors to address different aspects of GSCM in healthcare.

Table 1. Top journals by article count and citations on GSCM in healthcare.

Based on the number of articles				
Source	h-index	TC	Document	PY start
Sustainability (Switzerland)	5	301	8	2015
Journal of Cleaner Production	6	293	6	2018
Environmental Science and Pollution Research	5	63	5	2021
Technological Forecasting and Social Change	4	399	4	2021
International Journal of Environmental Research and Public Health	3	36	4	2019
Based on the number of citations				
Source	h-index	TC	Document	PY start
International Journal of Production Economics	1	665	2	2021
Technological Forecasting and Social Change	4	399	4	2021
Sustainability (Switzerland)	5	301	8	2015
Journal of Cleaner Production	6	293	6	2018
Transportation Research Part E: Logistics and Transportation Review	1	251	1	2014

Note: TC – total citations; PY – publication year.

Table 2. Top authors by article count and citations in GSCM in healthcare

Based on the number of citations						
Author	h-index	TC	Doc.	PY start	Affiliation	Ref.
Mahtab Kouhizadeh	1	665	1	2021	University of Rhode Island	(Kouhizadeh et al., 2021)
Sara Saberi	1	665	1	2021	Worcester Polytechnic Institute	(Kouhizadeh et al., 2021)
Joseph Sarkis	1	665	1	2021	Worcester Polytechnic Institute	(Kouhizadeh et al., 2021)
Omar Bentahar	2	293	2	2021	Université de Lorraine	(Bentahar et al., 2023; Benzidia et al., 2021b)
Benzidia Smail	2	293	2	2021	Université de Lorraine	(Benzidia et al., 2021b; Bentahar et al., 2023)
Naouel Makaoui	1	288	1	2021	ICD International Business School	(Benzidia et al., 2021b)
Based on the number of articles						
Author	h-index	TC	Doc.	PY start	Affiliation	Ref.
Govind Sharan Dangayach	3	35	3	2023	Malaviya National Institute of technology Jaipur	(Vishwakarma et al., 2022, 2023, 2024)
Sumit Gupta	3	35	3	2023	Amity University	(Vishwakarma et al., 2022, 2023, 2024)
Meena M.L.	3	35	3	2023	Malaviya National Institute of Technology Jaipur	(Vishwakarma et al., 2022, 2023, 2024)
Amit Vishwakarma	3	35	3	2023	IIT Kanpur	(Vishwakarma et al., 2022, 2023, 2024)
Salim Karimi Takalo	2	32	3	2018	Vali-e-Asr University of Rafsanjan	(Mirghafoori et al., 2018; Tooranloo et al., 2022)

Note: TC – total citations; PY – publication year; Ref – reference.

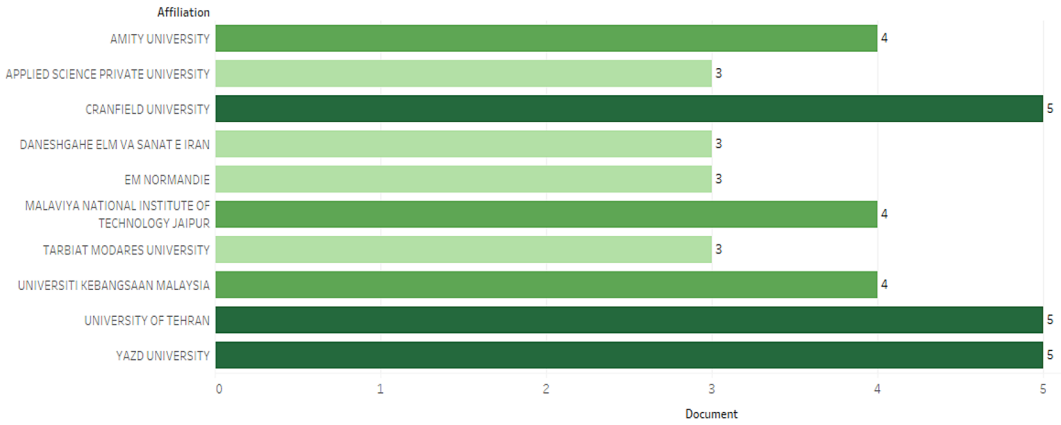

Figure 4. Top 10 institutions with the high number of publications in GSCM in healthcare

Top 10 publication affiliations

The affiliation analysis in Figure 4 shows that research on GSCM in the healthcare sector involves 160 affiliations from different academic institutions and organisations around the world. Yazd University, the University of Tehran and Cranfield University have the highest total number of published papers with 5 papers respectively. The strong presence of universities from developing countries, such as Universiti Kebangsaan Malaysia (Malaysia) and Malaviya National Institute of Technology Jaipur (India), with 4 publications each, highlights the important role these institutions play in the development of green supply chain management research in the healthcare sector. This is driven by the urgent need for sustainable solutions in healthcare systems in developing countries. The diversity of affiliations, including universities, research institutes and industry organisations from different countries, demonstrates the worldwide and multidisciplinary scope of research in this area. The involvement of institutions from different geographical and economic backgrounds reflects the importance of different perspectives in addressing the global challenges of green supply chain management in the healthcare sector.

Table 3. Top 5 most cited articles on GSCM in healthcare

Author	Journal	Country of first author	Main topic	Conclusion	TC	Ref.
Mahtab Kouhizadeh, Sara Saberi, Joseph Sarkis	International of Journal economics	Iceland	Blockchain technology for sustainable supply chains	Blockchain technology offers the prospect of improving supply chain transparency, operational efficiency and sustainability, but there are still barriers to its application that need to be overcome.	671	(Kouhizadeh et al., 2021)
Smail Benzidia, Naouel Makaoui & Omar Bentahar	Technological Forecasting & Social Change	France	Big data analytics and artificial intelligence for sustainable supply chains	Environmental process integration and green supply chain collaboration are positively impacted by the use of big data analytics and artificial intelligence, resulting in improved environmental performance.	293	(Benzidia et al., 2021b)
M.S. Pishvaee, J. Razmi & S.A. Torabi	Transportation Research Part E	Iran	Sustainable supply chain network design	A multi-objective programming approach for designing a sustainable supply chain for disposable syringes, incorporating economic, environmental, and social factors. To solve the model effectively, an accelerated Benders decomposition algorithm is employed.	251	(Pishvaee et al., 2014)
Haitham M. Alzoubi, Gouher Ahmed, Anwar Al-Gasaymeh & Barween Al Kurdid	Management Science Letters	Uni Arab Emirates	Sustainable supply chain strategy	Sustainable supply chain strategies have a positive impact on supply chain collaboration and competitive prioritization. Supply chain collaboration mediates these relationships.	149	(Alzoubi et al., 2020)
C.K.M. Lee & Jasmine Siu Lee Lam	Industrial Marketing Management	China	Sustainable industrial marketing and reverse logistics	The proposed framework for sustainable industrial marketing integrates green market analysis, green market development, sustainable operations management, and customer acquisition. It highlights that effective reverse logistics can play a crucial role in supporting sustainability.	137	(C. K. M. Lee & Lam, 2012)

TOP 5 MOST CITED ARTICLES

Keyword analysis

Network visualization

The keyword network visualization in Figure 5 provides valuable insights into the structure and focus of research on green supply chain management in the healthcare sector. The four main clusters identified illustrate the different aspects and approaches within this field. The green cluster focuses on aspects of sustainability and supply chain management. The main keywords include "sustainable development", "sustainability", "supply chain management", and "sustainable supply chains". This cluster links concepts such as the circular economy, Industry 4.0, artificial intelligence, and data analytics. This shows that research in this area emphasizes the development of sustainable supply chains by utilizing modern technologies and approaches.

The red cluster is related to environmental impact and decision-making. The main keywords include "green supply chain", "environmental impact", and "decision making". This cluster links concepts such as greenhouse gases, global warming, optimization, and life cycle analysis. This cluster illustrates the focus on reducing environmental impacts in the supply chain and the decision-making process of the supply chain. The blue cluster focuses on aspects of health and medical care. The main keywords in this cluster include "health care", "hospitals", and "medicine", showing connections to concepts such as logistics, healthcare, and public health. This cluster shows specific applications of sustainable supply

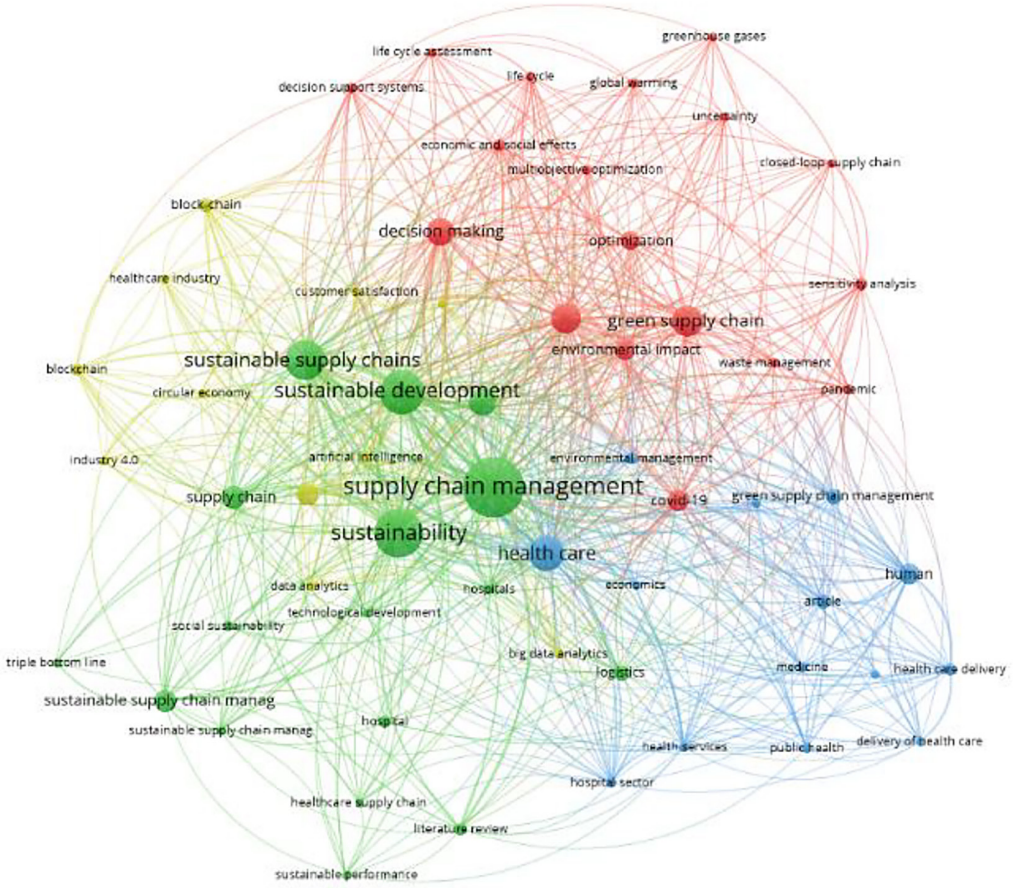

Figure 5 Network visualization of keywords for the research topic of green supply chain management in the healthcare sector

chain concepts in the healthcare sector. Although the yellow cluster has a smaller area, it focuses on blockchain technology and the healthcare industry. The existence of this cluster indicates a growing interest in the use of blockchain technology to improve sustainable supply chains in the healthcare sector (Revathi et al., 2024; Sun, 2024).

The varying node sizes indicate the frequency of occurrence of keywords in the literature. Keywords such as "sustainable development", "supply chain management", and "green supply chain" with the largest note size indicate that they are central keywords in this topic. This indicates that research in this field not only focuses on the environmental (green) aspect but also considers the economic and social aspects of environmental sustainability (Diddi & Tiwari, 2024).

The pattern of connections between clusters also provides interesting insights into research directions. For example, the strong connection between "blockchain" (yellow cluster) and "sustainable supply chains" (green cluster) indicates an emerging trend in the use of blockchain technology to improve the transparency and efficiency of sustainable supply chains in the healthcare sector (Zia et al., 2024). Moreover, the connections between "COVID-19" (blue cluster) and nodes in other clusters reflect the significant impact of the pandemic on sustainable healthcare supply chain research, driving a renewed focus on system resilience and flexibility (Zahari et al., 2024). The presence of keywords such as "circular economy" and "waste management" indicates the growing attention to circular economy principles in managing health supply chains, emphasizing the importance of resource efficiency and waste reduction (Sibonghanoy Groenewald et al., 2024).

Overlay visualization

The overlay visualization in Figure 6 provides valuable insights into the temporal evolution of research on green supply chain management in the healthcare sector. There is a clear shift in research focus from year to year, indicated by the color gradation from yellow (2020) to green

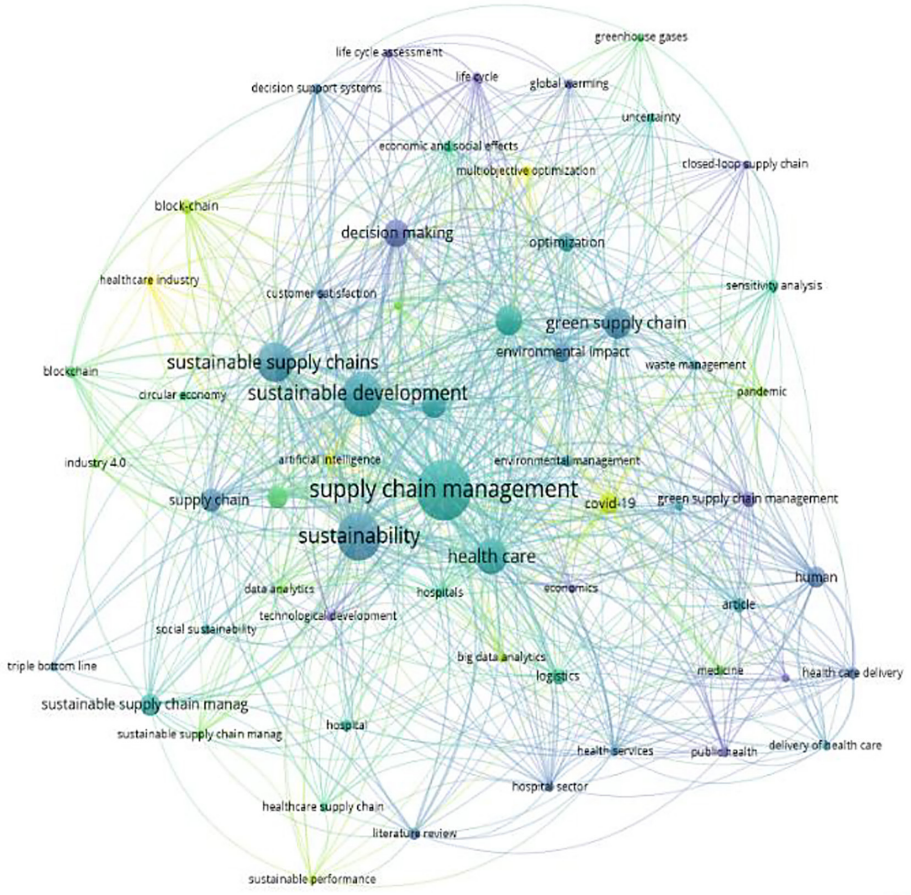

Figure 6. Visualization of keywords overlays by year for the research topic of green supply chain management in the healthcare sector

(2023). Core concepts such as "sustainable development", "supply chain management", and "sustainability" are shown in bright green, indicating that these topics remain a key focus and continue to evolve in recent research. This indicates that the integration of sustainability principles into healthcare supply chain management has remained a priority in recent years.

Interesting concepts in this study appear in blue to purple, such as "blockchain", "Industry 4.0", and "circular economy", illustrating more recent research trends. This shows that in recent years, there has been increased interest in integrating advanced technologies and circular economy principles into sustainable healthcare supply chains. The appearance of "COVID-19" in the same color spectrum also reflects how the pandemic has influenced research directions that are driving a renewed focus on the resilience and flexibility of health supply chain systems. Keywords such as "waste management", "environmental impact", and "greenhouse gases" appearing in the green–blue color spectrum indicate that the environmental aspects of the healthcare supply chain remain a consistent concern but with increasingly sophisticated approaches over time. The appearance of concepts such as "decision making", "optimization", and "multiobjective optimization" in brighter colors signifies the latest trends in the development of analytical tools and methods to support decision-making in sustainable healthcare supply chain management.

Future research directions

On the basis of the analysis of keyword data visualization for GSCM research topics in the healthcare sector, several future research directions can be identified. There is a strong trend of integration between advanced technologies and sustainability concepts in the healthcare supply chain. The main focus of research is likely to shift to the development and implementation of artificial intelligence, blockchain, and Industry 4.0 technologies to improve the efficiency and transparency of GSCM in healthcare facilities. In

addition, multi-objective optimization and complex decision-making are significant research areas, with the aim of simultaneously balancing operational efficiency, environmental impact, and quality of patient care.

Future research is also expected to place greater emphasis on comprehensive life cycle analysis and environmental impact assessment of healthcare products and services. This includes in-depth studies of greenhouse gas emissions, medical waste management, and the application of circular economy principles in healthcare supply chains. In line with this, the development of supply chain models that are more resilient and responsive to global health crises, such as the COVID-19 pandemic, will be an important focus. The use of big data analytics for GSCM optimization in the healthcare sector is also predicted to intensify, with the aims of increasing efficiency, reducing waste, and improving overall sustainability.

Innovation in environmentally friendly healthcare logistics is projected to constitute a growing research area, encompassing the development of more efficient transportation and storage methods for medical products. GSCM research in the healthcare sector is also expected to be increasingly aligned with the Sustainable Development Goals, which integrate environmental, social and economic aspects holistically. Future research directions are likely to be more interdisciplinary, combining various scientific fields to create health systems that are not only efficient and resilient but also sustainable and environmentally friendly.

CONCLUSIONS

This bibliometric analysis provides a complete overview of the development of green supply chain management (GSCM) research in the healthcare sector from 2002–2024. The results of the analysis show significant growth in the number of publications, with an average annual growth of 15.76%, indicating the increasing interest and urgency of this topic within the scientific community. Research contributions are spread globally, with India, Iran, China, the United States and the United Kingdom being the main contributors. The most influential journals analyzed were Sustainability (Switzerland) for the number of publications and the International Journal of Production Economics for the number of citations. The most influential authors were Mahtab Kohizade for the number of citations and Govind Dangayach, Sumit Gupta, Meena M.L., and Amit Vishwakarma for the total number of publications. Keyword analysis revealed four main clusters of research: (1) sustainability and supply chain management, (2) environmental impact and decision-making, (3) health and medical care, and (4) blockchain technology and the healthcare industry. Emerging trends show an intensified integration of advanced technologies (such as blockchain, artificial intelligence, and Industry 4.0) with GSCM in the healthcare sector. The COVID-19 pandemic has also influenced research directions, driving a focus on the resilience and flexibility of healthcare supply chain systems. Future research projections should focus on the integration of advanced technologies, multiobjective optimization, comprehensive life cycle analysis, the development of resilient supply chain models, green logistics innovations, and alignment with sustainable development goals. In conclusion, GSCM in the healthcare sector has evolved into a complex and interdisciplinary research field, reflecting the need for an efficient, resilient, and sustainable healthcare system. Further research is needed to explore the practical implementation of the identified concepts and evaluate the long-term impact of GSCM practices on the environmental and operational performance of the health sector.

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