

Exploring Research on Cold Chain Logistics through Bibliometric Analysis¹

Bibliyometrik Analiz Yoluyla Soğuk Zincir Lojistiği Alanındaki Araştırmaların İncelenmesi

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Abstract: The need to maintain the quality and safety of perishable products such as food and pharmaceuticals under optimal temperature conditions throughout the supply chain makes cold chain logistics a critical process. This has highlighted the importance of bibliometric analysis as a method for identifying research gaps in cold chain logistics, visualizing collaboration networks, and showcasing scientific contributions, all of which contribute to the development of the field. Based on this significant contribution of bibliometric analysis to the field of cold chain logistics, this study conducts descriptive and mapping analyses, including citation analysis and keyword frequency analysis, for 911 articles published between 2010 and 2024, using data obtained from the Web of Science (WoS) database. Utilizing bibliometric tools such as VOSviewer, this study demonstrates a significant increase in cold chain logistics research, particularly following the COVID-19 pandemic, and reveals that key contributions in the field focus on sustainability, technological innovations, and public health logistics. This study, which contributes to the development of sustainable and efficient cold chain logistics approaches for academics and practitioners, also presents dominant research themes, influential authors, and emerging trends regarding the evolution of the field.

Keywords: Cold Chain Logistics, Distribution Channel, Bibliometric Analysis, Knowledge Mapping, Co-Citation Analysis

JEL Classification: I15, L52, L66, L91

Öz: Gıda ve ilaç gibi kolay bozulabilen ürünlerin kalitesinin ve güvenliğinin tedarik zinciri boyunca optimum sıcaklık koşulları göz önünde bulundurularak sağlanması gerekliliği soğuk zincir lojistiğini hayati öneme sahip bir süreç haline getirmektedir. Bu durum, sınırlı sayıda araştırmacı tarafından ele alınan soğuk zincir lojistiğine ilişkin araştırma boşluklarının belirlenmesini, işbirliği ağlarının görselleştirilmesini ve bilimsel katkıların ortaya konmasını mümkün hale getiren bibliyometrik analiz yaklaşımını alanın gelişimine katkı sunacak önemli bir yöntem olarak öne çıkarmaktadır. Bibliyometrik analiz yaklaşımının soğuk zincir lojistiği alanına sunacağı bu anlamlı katkıdan hareketle, bu çalışmada Web of Science (WoS) veritabanından elde edilen verilere dayalı olarak, 2010 ile 2024 yılları arasında yayımlanmış olan 911 adet makale için; atıf analizi ve anahtar kelime sıklığı analizlerini de kapsayan betimsel ve haritalama analizleri gerçekleştirilmiştir. VOSviewer gibi bibliyometrik araçlardan yararlanılarak oluşturulan bu çalışma, özellikle COVID-19 pandemisi sonrasında

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soğuk zincir lojistiği araştırmalarında önemli bir artış olduğunu göstermekte ve alana ilişkin önemli katkıların sürdürülebilirlik, teknolojik yenilikler ve halk sağlığı lojistiği alanlarında yoğunlaştığını ortaya koymaktadır. Akademisyenler ve uygulayıcılar için sürdürülebilir ve verimli soğuk zincir lojistiği yaklaşımlarının geliştirilmesine katkıda bulunan bu çalışmada, alanın gelişimine ilişkin olarak baskın araştırma temaları, etkili yazarlar ve ortaya çıkan eğilimler de sunulmuştur.

Anahtar Sözcükler: Soğuk Zincir Lojistiği, Dağıtım Kanalı,, Bibliyometrik Analiz, Bilgi Haritalama, Ortak Atıf Analizi

JEL Sınıflandırması: I15, L52, L66, L91

1. Introduction

A cold chain refers to a specialized supply chain system for perishable goods that ensures the maintenance of appropriate temperature, humidity, light, and contamination controls (Bishara, 2006). This system is essential for preserving the quality and safety of various products, including food, pharmaceuticals, and chemicals, by keeping them in frozen, chilled, or fresh conditions to prevent degradation (Bishara, 2006; Chaudhuri et al., 2018; George, 2000; Zhang and Lam, 2018; Fatorachian and Pawar, 2025). To minimize perishability, prolong shelf life, and ensure the delivery of fresh products to outlying markets without quality loss, an integrated cold chain system incorporating components such as cold storage, refrigerated transport, and pre-cooling units plays a key role (Rangar et al., 2025). Without an effective cold chain management, supply chains may become vulnerable. Reflecting this, India, a leading country in agricultural production, experiences significant quantity and quality issues, with value losses reaching nearly 40% in the national fruit and vegetable supply chain (Negi and Anand, 2015; Yu and Xiao, 2021). Through loss minimization, cold chain also provides economic benefits to the public, including enhanced welfare for producers, accurate price realization, and the control of fluctuations in consumer prices (Rangar et al., 2025).

The COVID-19 pandemic significantly increased scientific interest in the cold chain logistics sector, as the global demand for efficient logistics systems to handle temperature-sensitive products like vaccines, pharmaceuticals, and perishable foods surged (Bamakan et al., 2021; Fahrni et al., 2022). Researchers began focusing more on such topics as optimizing cold chain management for pandemic resilience, enhancing storage and transportation technologies, integrating innovative solutions such as Internet of Things (IoT) and blockchain for real-time monitoring, traceability (Adekomaya et al., 2016; Guo et al., 2018; Alatepeli, 2022; Chen et al., 2022) and environmental sustainability of cold chain operations, addressing challenges like carbon emissions and energy efficiency (Liu, 2023; Saari, 2023). The intensification of academic inquiry has not only contributed to the expansion of the theoretical and empirical knowledge base but has also underscored the indispensable role of cold chain logistics in maintaining global health standards and ensuring food security.

Bibliometric analysis is a crucial tool for organizing and thematizing research on cold chain supply by systematically mapping existing studies and highlighting key trends and knowledge gaps. It enables the identification of influential studies, leading authors, and prominent journals, offering a comprehensive overview of the research field (Ellegaard and Wallin, 2015; Passas, 2024). By visualizing collaboration networks and emerging themes, bibliometric analysis provides insights into the evolution of the field. This not only facilitates the navigation of an increasingly complex corpus of knowledge for emerging scholars, but also directs their attention toward underexplored domains and prospective avenues for meaningful scholarly contributions. (Moral-Muñoz et al., 2020).

The primary objectives of this study are to: (1) provide a comprehensive analysis of the evolution of research in these disciplines and offer recommendations for future studies; (2) analyze the distribution of contributing countries and the most prolific journals in the identified topics; (3) evaluate the most commonly occurring keywords within the field; and (4) identify the leading authors contributing significantly to the research.

The primary motivation behind this study is to explore the research dynamics within the field of cold chain logistics, with a specific focus on identifying key discussions that shape its development, highlighting current and emerging trends, and uncovering unexplored areas of research. A comprehensive understanding of existing literature on cold chain logistics is essential for multiple reasons. First, it enables the systematic identification of research gaps and areas warranting further scholarly exploration. Moreover, it offers valuable insights for policymakers and industry practitioners by illuminating prevailing trends, technological advancements, and established best practices within the sector. Finally, it paves the way for academics and researchers to pursue collaborative initiatives and to explore innovative trajectories for future inquiry in the field of cold chain logistics.

2. Conceptual Framework

Cold chain logistics is a complex systems engineering approach aimed at maintaining products at specified low temperatures through refrigeration technologies (Zhang et al., 2019; Shi et al., 2022). According to another definition, cold chain logistics is a distinct branch of supply chain logistics focused on refrigeration techniques to ensure products remain at a specified temperature from production to the point of sale (He and Yin, 2021; Fan et al., 2020; Jackson et al., 2025).

From an international perspective, cold chain logistics encompasses all activities aimed at ensuring that exported/imported products—primarily food and pharmaceuticals—reach their destination without degradation, ultimately delivering them to the end consumer (Ceylan and

Danacı Ünal, 2023). Compared to other logistics operations, cold chain logistics faces unique challenges, including high operational costs, unpredictability, strict delivery requirements, rigorous qualification inspections, complex delivery conditions, high coordination needs, and traceability issues (Wen et al., 2019; İpekçi and Tanyaş, 2021). These challenges highlight that comprehensive risk identification related to product quality, quantity, and disruption times along the chain is essential (Bamakan et al., 2021). Moreover, there is a growing demand for more stringent legal frameworks concerning traceability in cold chain logistics, accompanied by the ongoing development of standardized and regulated traceability mechanisms. (Ruiz-Garcia and Lunadei, 2010). Especially, within the scope of food safety regulations, companies that fail to comply with temperature requirements may face legal sanctions and reputational damage (Jackson et al., 2025).

Given that the operations of temperature-sensitive goods are completed within hours, the supply chain management for such goods is highly complex and requires rapid decision-making skills (Ruiz-Garcia and Lunadei, 2010). Thus, outsourcing cold chain activities to specialized Logistics Service Providers (LSPs), have an immense experience and specialized resources to successfully implement and handle cold chain activities is a commonly adopted strategy by firms to minimize operational costs and concentrate on their main activities (Jackson et al., 2025).

Various transport vehicles and units, such as trucks, containers, and rail wagons, can be adapted for cold chain logistics through modifications in temperature-controlled transport operations (İpekçi and Tanyaş, 2021). Due to the considerable distance between production centers and markets within the cold chain, lead times tend to be long and variable (Cai et al., 2013; Jackson et al., 2025). Although perishable products are transported both domestically and internationally to preserve their value (Ali et al., 2018), the transportation process is intended to be completed in a cost-effective manner (Lu et al., 2021). Among the various modes of transportation, road transport remains the most widely utilized within the cold chain logistics sector, despite its association with high carbon emissions and its status as the least cost-effective, least environmentally sustainable, and least operationally efficient option for retail cold chain activities (Shi et al., 2022; Boyer et al., 2009; İpekçi and Tanyaş, 2021). In addition, while door-to-door operations are not feasible in maritime and rail transportation, road transport plays a complementary role in delivering products from ports to warehouses, providing nationwide reach (İpekçi and Tanyaş, 2021). The fact that approximately 90% of cold chain logistics operations are carried out via road transportation underscores the critical role this mode plays within the broader cold chain logistics framework (Liu, 2023). In light of

this, it can be contended that although cold chain logistics contributes significantly to economic development, its heavy reliance on energy-intensive refrigerated equipment renders it a substantial environmental concern, primarily due to elevated levels of CO₂ emissions, greenhouse gases, and air pollutants (Wang et al., 2018). The selection of a multimodal transport alternative for managing cold chain logistics can be successful due to its superiority in terms of safety, efficiency, and environmental sustainability (Liu, 2023). For example, in terms of freight rates, rail transportation offers a competitive advantage over road and air transport modes for medium and long-distance shipments (Lu et al., 2021), whereas air transport offers a competitive advantage for perishable products since its cost and environmental impacts limit its use in cold chain operations (İpekçi and Tanyaş, 2021). Due to the rapid pace of the process, which is influenced by external environmental factors and the adaptability challenges among different transportation modes, managing cold chain logistics within a multimodal transport framework becomes complex (Liu, 2023). The storage process in the cold chain requires refrigeration and freezing storage equipment (Masudin and Safitri, 2020). Refrigerated storage is currently a widely used technique for preserving perishable foods (Uçar and Özçelik, 2013).

Furthermore, since cold chain logistics has specific and stringent requirements compared to other logistics sectors, businesses in this field face challenges in meeting customer demands (Lim et al., 2021; Kuo and Chen, 2010). Given today's market conditions, where consumers increasingly prioritize food safety and pharmaceutical quality, a company's competitiveness and customer satisfaction are directly linked to effective and efficient cold chain logistics. (Xia and Shi, 2024). Thus, firms must develop innovative and differentiated strategies to establish themselves as leaders with a loyal customer base (Lim et al., 2021). These challenges have given rise to an expanding body of academic research aimed at identifying key customer selection criteria and developing strategies to mitigate carbon emissions within cold chain logistics.

Recently, the increased awareness of cold chain logistics due to the COVID-19 pandemic has led to a rise in academic research in this field. Accordingly, this study seeks to offer comprehensive guidelines for researchers in the field by conducting a bibliometric analysis to identify seminal scientific works in cold chain logistics, the most prevalent research topics, the most frequently cited authors, and the key organizations driving this area of study.

3. Methodology

The systematic literature review approach, which explains research trends in a specific academic research area (Li et al., 2024), allows for the examination of a smaller number of

publications by focusing on a narrower research scope (Snyder, 2019; Donthu et al., 2021). Unlike this method, which predominantly relies on qualitative techniques and provides a subjective evaluation opportunity (MacCoun, 1998; Donthu et al., 2021), bibliometric analysis enables analyses such as keyword analysis, author analysis, and/or citation analysis based on quantitative data (Ragazou et al., 2022; Chen and Xiao, 2016; Zupic and Čater, 2015; Donthu et al., 2021; Passas, 2024), thereby avoiding subjectivity (Donthu et al., 2021).

Another related methodology, the meta-analysis approach, which is used to estimate the variance across studies in a given field and to identify the overall strength and direction of effects (Passas, 2024), primarily aims to contribute to theory development (DerSimonian and Laird, 1986; Liberati et al., 2009). It systematically evaluates the literature in a specific field, typically through manual review (Torraco, 2005). While it is valuable for synthesizing nuanced evaluations within a specific field by focusing on a large body of literature, the method has notable limitations, including publication bias and heterogeneity (Passas, 2024).

In addition to the challenges associated with systematic literature reviews and meta-analysis, which are commonly used research methods for interpreting large, unstructured datasets, bibliometric analysis has gained increasing popularity due to its advantages in terms of development, suitability, and accessibility. This is particularly evident through the application of bibliometric software tools, such as VOSviewer, Gephi, and Leximancer, in conjunction with renowned scientific databases, including Scopus and Web of Science (WoS). Bibliometric analysis offers a comprehensive overview through a single source, identifies knowledge gaps, and generates new research ideas (Donthu et al., 2021; Passas, 2024). For researchers, it uncovers collaboration patterns, publication trends, and journal performance (Verma and Gustafsson, 2020; Ragazou et al., 2022; Passas et al., 2022; Abramo and D'Angelo, 2014; Passas, 2024). Thus, bibliometric analysis is a powerful statistical method utilized to evaluate the quality and quantity of scientific literature and to explore research trends and citation dynamics within a specific field (Donthu et al., 2021). First introduced by Pritchard in 1969, this method offers various advantages, with its primary strength being the ability to perform quantitative assessments using measurable, objective, and readily available data derived from coded information (Maliha, 2023). As a versatile and effective tool, bibliometric analysis has proven invaluable for identifying research patterns and trends across various academic disciplines (Ellegaard and Wallin, 2015; Passas, 2024). Moreover, it functions as a multifaceted instrument that enables scholars to pursue a range of research objectives, including the identification of emerging trends in article and journal performance, the analysis of collaboration networks, and the investigation of the intellectual structure

within a particular field of study (Donthu et al., 2021; Passas, 2024). However, bibliometric analysis typically entails the processing of large-scale datasets, often comprising hundreds or even thousands of records, and is guided by objective metrics such as citation counts, publication volumes, keyword frequencies, and topic distributions. This data is fundamentally derived from bibliographic metadata of various document types, primarily relying on indexing and citation databases that provide expansive yet inherently constrained datasets (Bredahl, 2022). The advent of scientific databases like Scopus and WoS has significantly simplified the acquisition of extensive bibliometric datasets. Additionally, the advancement of analytical tools such as Gephi, Biblioshiny, and CiteSpace has significantly facilitated the analysis of bibliometric datasets, thereby contributing to the increasing adoption of bibliometric methods by scholars in recent years (Ellegaard and Wallin, 2015; Moral-Muñoz et al., 2020).

The main reason for choosing WoS in this study is its standardized data structure and high level of selective indexing. Through its strict acceptance criteria, it provides a homogeneous set of studies that is highly trustworthy. On the other hand, Google Scholar may introduce inconsistencies in bibliometric analysis, as it does not provide transparent criteria for its indexing process and includes sources such as reports, theses, and presentations, whose academic quality varies. Likewise, Scopus does not provide the same level of assurance as WoS, since it does not implement a selective indexing policy. In addition, standardized citation styles, accuracy in author name disambiguation, and consistency in address information in WoS strengthen data consistency and methodological reliability. Commonly used software, such as VOSviewer, CiteSpace, and Bibliometrix, is compatible with the WoS format.

Although this study exclusively utilized the Web of Science Core Collection to ensure data quality, consistency, and the inclusion of peer-reviewed scholarly publications, we acknowledge that integrating additional databases such as Scopus and Google Scholar in future research would enhance the comprehensiveness and cross-validation of bibliometric findings. Such multi-database integration could provide broader coverage of emerging publications, conference proceedings, and regional journals, thereby contributing to a more holistic understanding of research evolution within the cold chain logistics domain.

Although the number of academic studies examining cold chain logistics using bibliometric analysis is limited, it is evident that research in the field of cold chain logistics has experienced a significant increase in recent years. The reviewed studies on cold chain logistics employ diverse methodological approaches to identify research trends, map collaboration networks, and highlight emerging challenges in the field. Among these studies,

Vrat et al. (2018) utilized Literature Review Analytics (LRA) to examine sustainability issues in perishable goods logistics, analyzing 216 studies spanning 1985 to 2017. Kang et al. (2021) leveraged CiteSpace to analyze 681 articles, identifying trends in smart and sustainable cold chain logistics in China. Similarly, Hu et al. (2024) used CiteSpace, VOSviewer, and Bibliometrix to explore 1,787 articles, focusing on seafood logistics and constructing knowledge maps to highlight emerging hotspots. Qi and Li (2024) analyzed 7,381 articles using CiteSpace to examine vehicle routing problems, emphasizing multi-objective optimization and interdisciplinary solutions. Shashi et al. (2021) applied VOSviewer for co-citation analysis in food cold chain logistics, revealing the importance of RFID (Radio Frequency Identification) and IoT technologies. Mustafa et al. (2024) adopted VOSviewer and Biblioshiny to analyze 114 publications, highlighting six key clusters, including sustainability and technological advancements. These studies, taken together, apply bibliometric methodologies to elucidate the dynamic and evolving contours of research in cold chain logistics (Vrat et al., 2018; Shashi et al., 2021; Kang et al., 2021; Hu et al., 2024; Mustafa et al., 2024; Qi and Li, 2024).

Recent research reveals substantial growth and diversification in the field of food cold chain logistics, emphasizing sustainability and technological innovation. Baladraf and Marimin (2025) reported an annual expansion rate of 12.26%, highlighting the increasing adoption of RFID and IoT systems to improve food safety and operational resilience, while Hu et al. (2024) identified critical research gaps in seafood cold chain logistics, particularly in operational optimization and efficiency improvement. Complementing these insights, Maharani and Hartati (2023) demonstrated that cold chain logistics optimization benefits significantly from advancements in vehicle routing, carbon emission reduction, and the application of phase change materials for thermal regulation. Similarly, Karanam et al. (2025) identified emerging themes that point toward an interdisciplinary integration of logistics management, environmental sustainability, and digital transformation, stressing the need for methodological innovation to close existing research gaps. In a related context, Andoh and Yu (2022) provided foundational perspectives on vaccine distribution logistics, underscoring the vital role of robust cold chain systems in ensuring timely and safe delivery during public health crises. Collectively, these studies indicate a paradigm shift toward sustainable and technology-enabled frameworks in cold chain logistics, reflecting an evolution from traditional operational models to more data-driven, adaptive, and resilience-oriented systems.

Unlike these studies, this study aims to provide a comprehensive perspective by examining cold chain logistics through a holistic approach, rather than focusing on a specific

subfield or its relationship with another topic. To this end, the study employs a bibliometric analysis to investigate research trends, collaboration networks, and thematic developments in the field of cold chain logistics. Furthermore, this study utilized the WoS database, considering that publications obtained from this database are likely to be duplicated in other databases (e.g., Google Scholar and Scopus) (Harzing and Alakangas, 2016; Qi and Li, 2024), and that research conducted within this database provides access to prominent publications with high international recognition in their respective fields (Li et al., 2024). This approach ensured the construction of a dataset capable of yielding reliable, globally representative, and methodologically sound results.

In this study, term co-occurrence analysis and science mapping analysis were employed to uncover the major themes within the research domain. The visualized maps generated by VOSviewer consist of nodes and edges, where nodes represent keywords, and edges illustrate the relationships and connections between these keywords (Ellegaard and Wallin, 2015). This methodological framework provides a comprehensive and systematic understanding of the scientific landscape in cold chain logistics, facilitating meaningful insights and future research directions.

The data retrieved from the Web of Science Core Collection on November 5, 2024, include articles, books, book chapters and reviews, published between 2010 and 2024. Owing to its long-standing inclusion of numerous high-quality and leading journals, its compatibility with visual analysis techniques, and the consistency of results across various databases, this study employed the Web of Science Core Collection as the primary data source (Qi and Li, 2024). The search strategy involved using keywords such as *cold chain* and *logistics* within the topic field. The resulting dataset was subsequently refined through the application of exclusion criteria, including the removal of duplicate records, unrelated subjects, and non-English publications.

The processed data were analyzed by using bibliometric software tools, including VOSviewer version 1.6.20 and Tableau Desktop version 2022.4 to visualize co-authorship networks, keyword co-occurrence maps, and citation relationships. Descriptive and statistical analyses were carried out to identify dominant research themes, leading authors, influential journals and institutions, as well as emerging trends in the field. In addition, cluster analysis was conducted to map the thematic structure of the literature. The overall methodological process is illustrated in Figure 1.

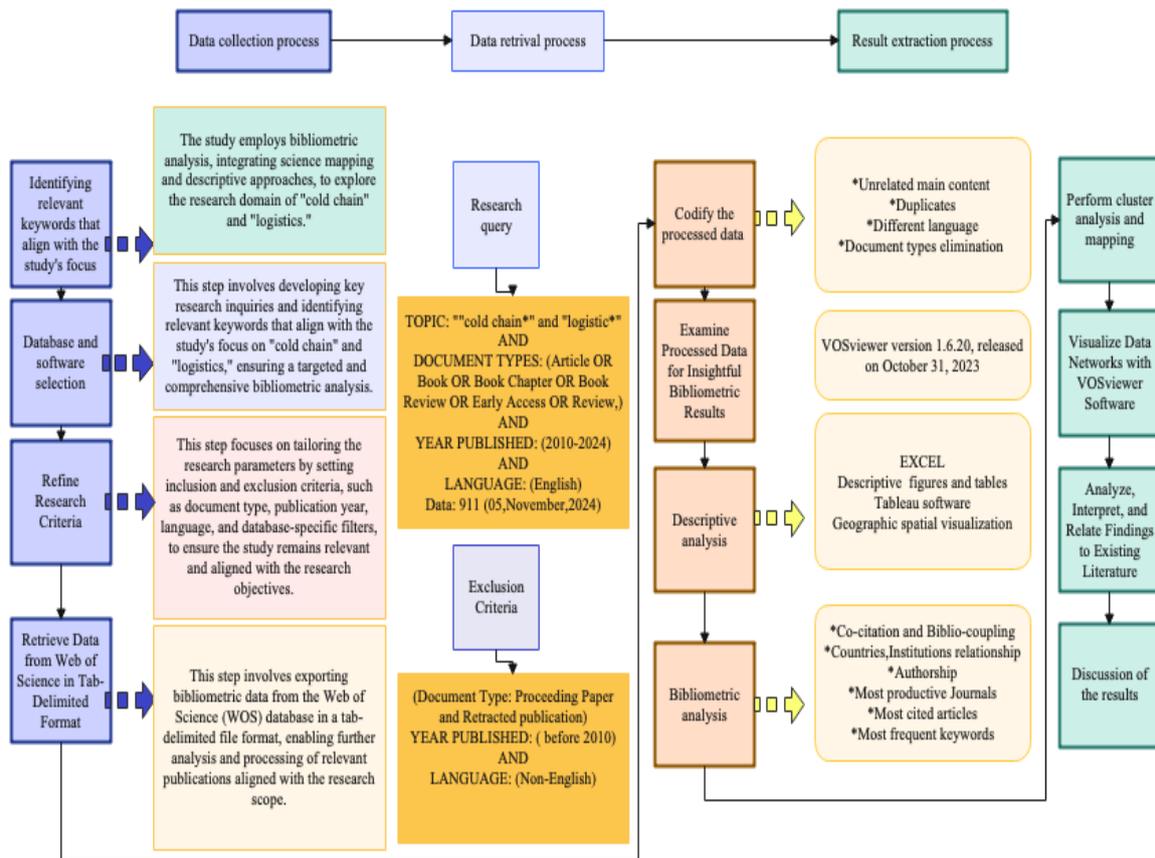


Figure 1. The Flow Chart of Methodology

The data analysis was conducted in two stages. In the first stage, Tableau software was utilized for a statistical examination of bibliometric data to identify the most cited articles and the leading countries based on impact factor and SCImago Journal Rank (SJR) metrics. In the second stage, bibliometric maps were generated by using VOSviewer software, employing techniques such as author co-citation analysis, bibliographic coupling, and keyword co-occurrence mapping to visualize the research field. Furthermore, this study seeks to identify existing research gaps and thereby provide direction for future scholarly investigations. To fulfill this objective, the following search terms were incorporated into the Web of Science (WoS) queries: 911=((TS=("Cold Chain" and "Logistic*") AND DT=(Article OR Book OR Book Chapter OR Book Review OR Review)) AND PY=(2010-2024), AND LA=(English))

4. Findings

The dataset employed in this study comprises bibliometric records from 911 publications on cold chain logistics, covering the period from 2010 to 2024. It encompasses key indicators such as annual publication volumes, citation trends, and thematic distributions, thereby facilitating a comprehensive analysis of the field's development over time. The visualization revealed a marked increase in both the number of publications and citations over the years,

with a particularly notable surge after 2020—likely reflecting the intensified scholarly attention to cold chain logistics in response to the COVID-19 pandemic. Additionally, the data provides valuable insights into the geographical distribution of research, the most frequently explored topics, and patterns of collaboration among researchers and institutions, thereby offering a robust foundation for trend analysis and the identification of research gaps in the field of cold chain logistics. Figure 2 illustrates the number of citations and publications from 2010 to 2024.

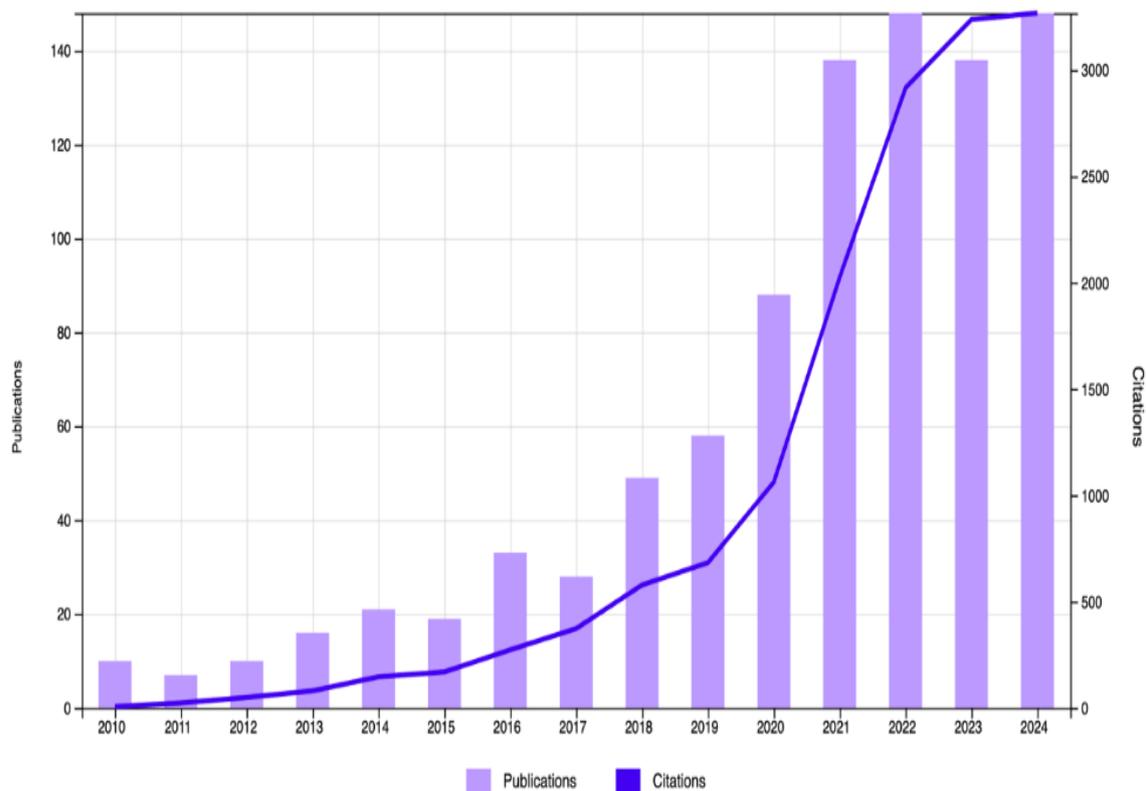


Figure 2. Number of Citations and Publications Between 2010 and 2024

While the number of publications grew steadily, as illustrated in Figure 2, citation counts experienced an exponential increase, underscoring the growing relevance and impact of the field in both academic and practical contexts. The sharp surge in research after 2020 suggests a shift toward addressing challenges arising from the pandemic, including innovations in vaccine cold chain management, sustainability in logistics, and advancements in traceability technologies such as blockchain and IoT. The rise in publications reflects an expansion of research themes, including sustainability, technology integration, and logistics optimization, indicating that cold chain logistics is evolving into a more interdisciplinary field. Figure 3 illustrates the distribution of the most productive countries in terms of article publications, generated using Tableau Desktop version 2022.4 visualization software.



Figure 3. Geographical Distribution Map of the Most Productive Countries in Article Publications

The analysis reveals significant disparities in cold chain logistics research across countries, as depicted in Figure 3. China leads with 512 publications, reflecting its focus on leveraging technology for global trade logistics. The United States of America (USA) follows with 111 publications, concentrating on food safety and advanced technologies such as IoT and blockchain. India, with 55 publications, highlights the attention of developing nations to local challenges, such as reducing food waste and improving infrastructure. European countries, including the United Kingdom (59), Germany (24), and France (18), emphasize sustainability and environmental concerns, while South Korea (30) and Japan focus on technology-driven solutions. Australia and South Africa (26 each) investigate cold chain adaptations for regional challenges, and Canada (23) tailors its logistics to its vast geography and extreme climates.

China, as one of the countries with the largest populations worldwide, is traditionally an agricultural nation characterized by both the production and consumption of perishable goods such as vegetables and fruits (Zhao et al., 2018; Wang, 2024). Driven by major factors such as

economic development, shifts in food demand, and cold chain regulations, cold chain development in eastern and southern China is more advanced than in western and northern regions (Dong et al., 2020). In addition, despite its relatively low but rapidly expanding cold chain coverage compared to that of developed nations (Dong et al., 2020; Wang, 2024), logistical challenges in accessing rural areas contribute to regional inequalities in cold chain development (Wang, 2024). These distinctive characteristics are regarded to contribute to China's academic productivity in this field.

India, recognized as an agrarian economy with diverse agro-climatic regions suitable for cultivating vegetables, fruits, spices, and flowers, is among the world's leading producers of horticultural crops such as bananas, lemons, and mangoes (Singh and Negi, 2018; Rangar et al., 2025). Ranked second globally in food production after China, the country requires cold storage infrastructure as a critical component to support the sustainability of its agriculture-based economy (Singh and Negi, 2018). However, the concept of a "cold supply chain" remains relatively new in India (Arora et al., 2023). Such characteristics are thought to be key drivers of China's scholarly output in the area of cold chain logistics.

With its scale and innovation capacity in key industries such as pharmaceuticals, agriculture, and retail, along with its provision of state-of-the-art logistics technologies and services worldwide, the USA maintains a leading position in cold chain logistics capabilities (Pajic et al., 2024; International Trade Administration, 2025). The competitive advantage of the USA in cold chain logistics can be attributed to its substantial academic productivity in this field.

This disparity highlights the urgent need for global collaboration to facilitate the exchange of technological advancements and address the gaps between developed and developing regions in cold chain logistics. Figure 4 illustrates the distribution across the primary WoS categories.

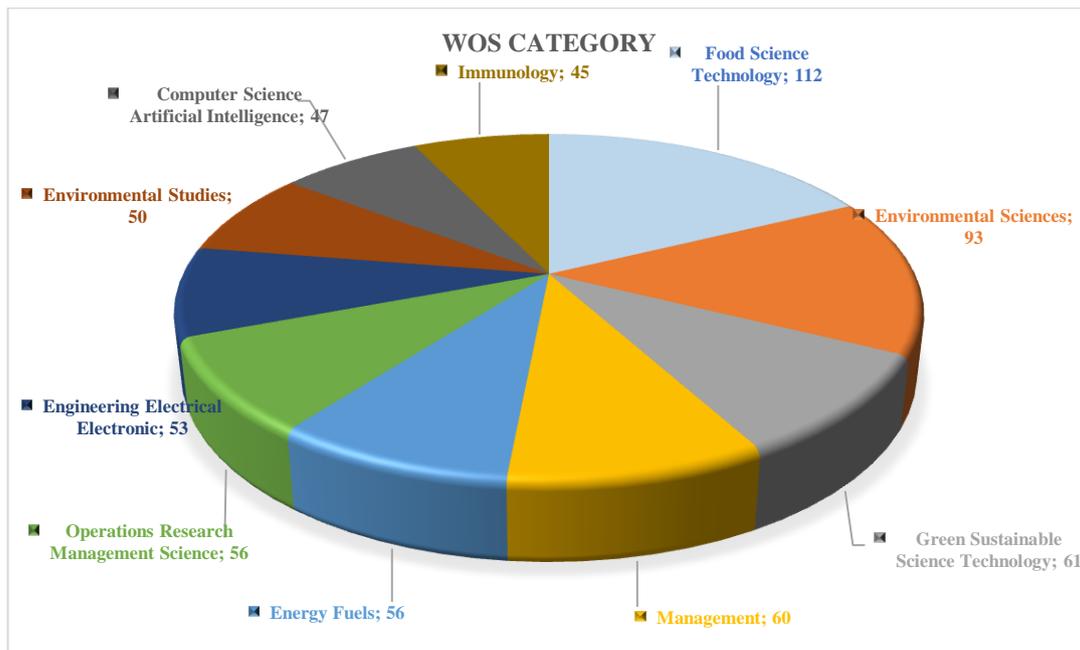


Figure 4. Distribution of Categories in the WoS

The WoS categories in cold chain logistics research highlight its interdisciplinary nature. Food Science and Technology leads with 112 publications, emphasizing its crucial role in food preservation and safety. This is followed by Environmental Sciences (93) and Green Sustainable Science and Technology (61), reflecting the increasing focus on sustainability, carbon footprint reduction, and energy efficiency within cold chain operations. These categories underscore the importance of aligning technological advancements with environmental sustainability and resource efficiency considerations.

Key topics driving food science research in the context of cold chain logistics include food safety, preservation techniques, and quality assurance. Research is heavily focused on maintaining optimal temperature conditions throughout the supply chain to prevent spoilage and extend shelf life, particularly for perishable goods like meat, dairy, fruits, and vegetables. Sustainability also emerges as a critical theme, with numerous studies exploring strategies to minimize energy consumption and carbon emissions in food transportation and storage. Moreover, the integration of advanced technologies—such as the Internet of Things (IoT), blockchain, and RFID—has received considerable attention for its potential to enhance traceability, monitoring, and operational efficiency within food logistics systems.

Table 1. Most Cited Articles bu Using the Query Terms “ Cold Chain” and “Logistics”

<i>Authors, year</i>	<i>Journal</i>	<i>Abstract -Index (2023) and WOS category</i>	<i>Methodology of the research</i>	<i>Aim of the research</i>	<i>Total Citation</i>	<i>Cold Chain Logistics category and Specialized cargo type of dataset</i>
Porat et al., 2018	Postharvest Biology and Technology	Science Citation Index Expanded (SCIE), Q1-Food Science and Technology	The research employs a comprehensive review of existing studies, using data from international organizations (e.g., FAO, WRAP, USDA) and detailed case studies from various countries. Quantitative analyses of food loss percentages are conducted across supply chain stages, supported by surveys, interviews, and real-world data on retail and household losses.	To reduce fruit and vegetable (F&V) losses, it reviews global data, and highlights logistics inefficiencies and consumer behaviors as key causes, proposing technological solutions and awareness campaigns	233	Temperature-Controlled Storage, Chilled Goods Handling
Wang et al., 2020	Aaps Pharmscitech	Science Citation Index Expanded (SCIE), Q2-Pharmacology and Technology	The study reviews vaccine candidates, focusing on their types, compositions, advantages, limitations, and stabilization strategies.	To evaluate the challenges and opportunities in COVID-19 vaccine formulation for effective development, distribution, and vaccination.	200	Temperature-Controlled Storage, Pharmaceuticals and Medical Goods
Tan et al., 2021	Nature Communications	Science Citation Index Expanded (SCIE), Q1-Multidisciplinary Sciences	The study utilizes SpyTag/SpyCatcher technology to conjugate the receptor-binding domain (RBD) of SARS-CoV-2 onto virus-like particles (VLPs) and evaluates the vaccine's efficacy and stability through preclinical testing in mice and pigs.	To develop a COVID-19 vaccine candidate using SpyCatcher technology to enhance immunogenicity and address challenges of stability and distribution.	185	Temperature-Controlled Storage, Pharmaceuticals and Medical Goods
Chianella et al., 2013	Analytical Chemistry	Science Citation Index Expanded (SCIE), Q1-Chemistry, Analytical	NanoMIPs were synthesized via solid-phase methods, characterized, and integrated into a competitive binding assay optimized for vancomycin detection in buffer and plasma.	To develop a highly specific and sensitive ELISA-like assay for vancomycin using molecularly imprinted polymer nanoparticles (nanoMIPs) as a replacement for antibodies.	172	Temperature-Controlled Storage, Chemical and Industrial Goods
Han et al., 2021b	Environmental Chemistry Letters	Science Citation Index Expanded (SCIE), Q1-Environmental Sciences	The study reviews evidence on SARS-CoV-2 stability under low temperatures, transmission risks along the cold chain, and incidents of contamination, incorporating laboratory studies and outbreak reports.	To assess the potential for foodborne transmission of SARS-CoV-2 and its implications for food safety and public health	165	Temperature-Controlled Storage, Pharmaceuticals and Medical Goods
Kuo and Chen, 2010	Food Control	Science Citation Index Expanded (SCIE), Q1-Food Science and	The study applies a problem-solving regulative cycle, integrating innovative cold chain technologies like cold boxes and eutectic plates with a	To develop a Multi-Temperature Joint Distribution (MTJD) system for optimizing cold chain logistics for	149	Temperature-Controlled Storage, High-Value

		<i>Technology</i>	<i>resource and service integration framework.</i>	<i>perishable food products</i>		<i>Perishables</i>
<i>Han et al., 2021a</i>	<i>Trends in Food Science & Technology</i>	<i>Science Citation Index Expanded (SCIE), Q1-Food Science and Technology</i>	<i>The study synthesizes data on cold chain logistics infrastructure, technologies, and policies, comparing China's cold chain development with that of developed countries</i>	<i>To provide a comprehensive review of cold chain logistics for fresh agricultural products, focusing on current practices, challenges, and future trends</i>	142	<i>Temperature-Controlled Storage, Bulk Perishables</i>
<i>Singh et al., 2018</i>	<i>Annals of Operations Research</i>	<i>Science Citation Index Expanded (SCIE), Q1-Operations Research and Management Science</i>	<i>The study uses a hybrid Fuzzy AHP and Fuzzy TOPSIS approach to evaluate and rank 3PL providers based on criteria like cost, infrastructure, innovation, and IT capabilities</i>	<i>To develop a decision-making framework for selecting third-party logistics providers (3PL) for cold chain management</i>	134	<i>Temperature-Controlled Storage, Chilled Goods Handling</i>
<i>Vrdoljak et al., 2012</i>	<i>Journal of Controlled Release</i>	<i>Science Citation Index Expanded (SCIE), Q1-Pharmacology and Technology</i>	<i>The study utilizes spray-coating techniques to coat microneedles with live viral vectors and evaluates their viability, delivery efficiency, and immunogenic response in preclinical models</i>	<i>To develop and optimize microneedle arrays for the transcutaneous delivery of live virus vaccines as a needle-free and stable immunization platform</i>	134	<i>Temperature-Controlled Storage, Pharmaceuticals and Medical Goods</i>
<i>Zaffran et al., 2013</i>	<i>Vaccine</i>	<i>Science Citation Index Expanded (SCIE), Q2-Medicine, Research and Experimental</i>	<i>The study reviews existing vaccine supply chains, evaluates global data on logistical issues, and outlines a global vision with key objectives for 2020, supported by detailed action plans</i>	<i>To address critical challenges in vaccine supply and logistics systems and propose solutions to enhance their efficiency and sustainability</i>	124	<i>Temperature-Controlled Storage, Pharmaceuticals and Medical Goods</i>

The analysis of the most cited research in cold chain logistics highlights key themes and significant contributions across diverse domains. Studies focusing on pharmaceutical logistics, such as those by Wang et al., (2020) and Tan et al., (2021), emphasize the challenges of vaccine storage and distribution, particularly during the COVID-19 pandemic, underscoring the critical role of temperature-controlled systems in ensuring efficacy. Similarly, Han et al. (2021b) explores the public health implications of cold chain logistics, including the potential transmission risks of SARS-CoV-2, reflecting the intersection of logistics and health. In the food sector, research by Porat et al., (2018) and Kuo and Chen (2010) address the reduction of food loss through innovative systems like Multi-Temperature Joint Distribution (MTJD), highlighting sustainability and efficiency in handling perishables. Technological advancements—such as the use of nanoMIPs for chemical detection (Chianella et al., 2013) and the application of fuzzy decision-making frameworks for third-party logistics selection (Singh et al., 2018) —exemplify the integration of cutting-edge methodologies into cold chain logistics. Collectively, these studies highlight the interdisciplinary nature of the field, with a pronounced emphasis on tackling global challenges related to food security,

public health, and environmental sustainability through innovative logistics solutions. Figure 5 presents the keyword co-occurrence network in cold chain logistics research, accompanied by relevant numerical insights.

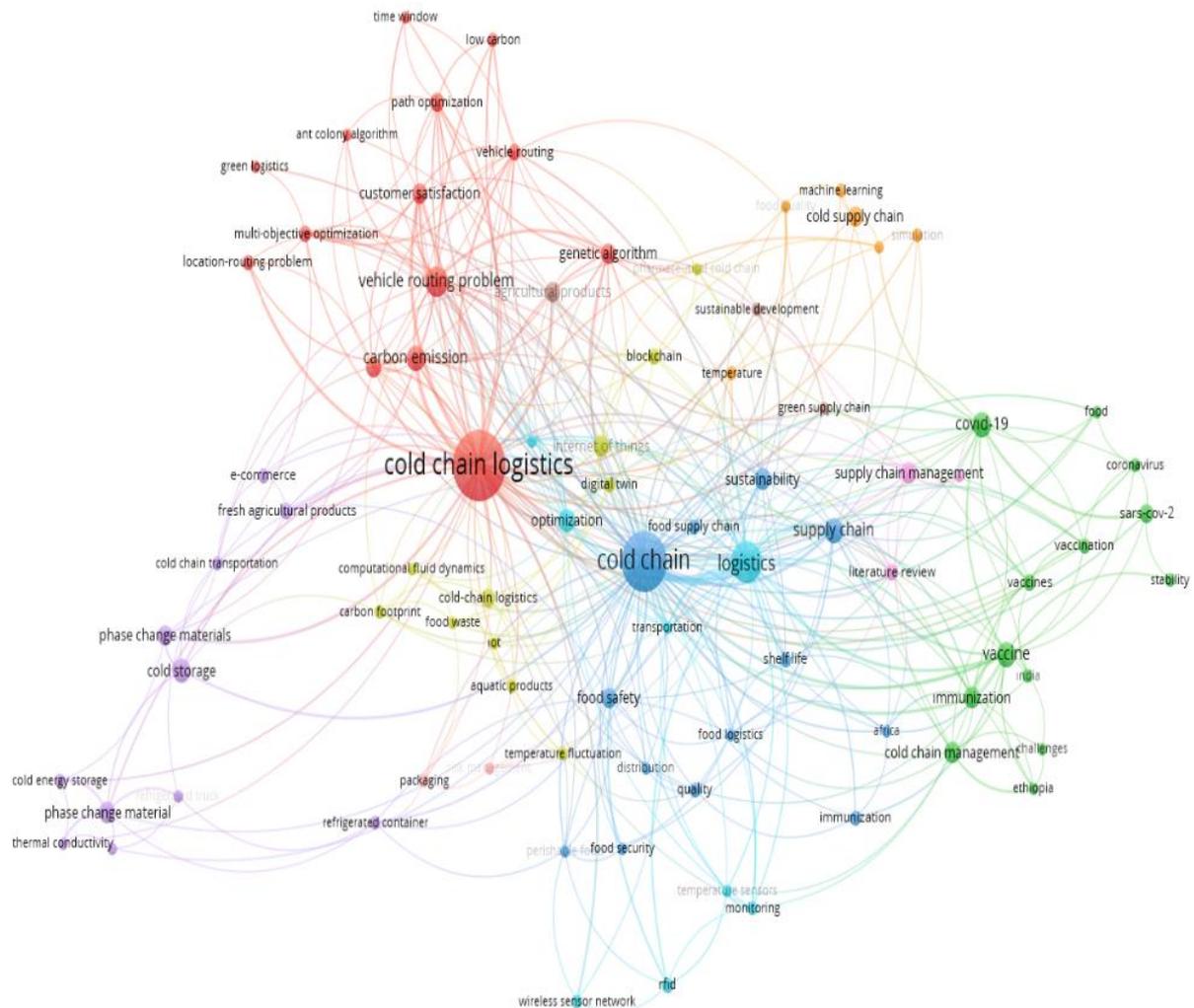


Figure 5. Network Visualization of Keywords Co-occurrence

The keyword co-occurrence analysis provides a clear representation of research priorities and their interconnections within cold chain logistics, supported by quantitative insights. The central keyword, *cold chain logistics*, appears 146 times with a total link strength of 147, highlighting its foundational significance in the field. Closely related terms such as “*cold chain*” (109 occurrences, 150 total link strength) and “*logistics*” (53 occurrences, 108 total link strength) further underscore the centrality of supply chain management within the field.

Pandemic-related keywords—such as *COVID-19* (20 occurrences, 26 link strength), *vaccine* (20 occurrences, 38 link strength), and *immunization* (14 occurrences, 25 link strength) —highlight the critical role of cold chain systems in global public health, particularly in the distribution of vaccines. Meanwhile, environmental concerns are reflected

in terms like *carbon emission* (20 occurrences, 26 link strength) and *sustainability* (14 occurrences, 25 link strength), indicating a growing research focus on minimizing the environmental footprint of logistics operations.

Technological innovation is evidenced by keywords such as *IoT* (15 occurrences, 16 link strength) and *optimization* (16 occurrences, 27 link strength), reflecting ongoing efforts to improve efficiency and decision-making processes within cold chain systems. Application-specific terms—including *cold storage* (19 occurrences, 33 link strength), *agricultural products* (13 occurrences, 22 link strength), and *food safety* (12 occurrences, 18 link strength)—underscore the essential role of cold chains in preserving perishable goods and upholding quality and safety standards. Collectively, these quantitative insights highlight the interdisciplinary nature of cold chain logistics research, which simultaneously addresses key global challenges such as pandemic response, environmental sustainability, and technological integration, while reinforcing the foundational importance of logistics operations.

The intersection between the red and blue clusters signifies an increasing convergence between traditional supply chain management and healthcare logistics, particularly after the COVID-19 pandemic. This overlap reflects how research priorities have shifted from food and agricultural logistics toward resilience and adaptability in health-related and emergency contexts. A temporal overlay of keyword occurrences further indicates that prior to 2020, studies primarily emphasized operational efficiency and “temperature control,” while the post-2020 period demonstrates a paradigmatic transition toward “vaccine logistics,” “resilience,” and “sustainability.”

The clustering pattern also reflects regional research orientations: Asian-led studies predominantly focus on technological and operational efficiency (e.g., IoT, optimization), whereas European and North American research streams prioritize sustainability and policy frameworks related to carbon emissions. The spatial proximity of terms such as “blockchain,” “green logistics,” and “public health” across clusters confirms the multidisciplinary character of the field, linking environmental science, digital technologies, and health management within a unified analytical framework. These patterns suggest that future research should integrate data-driven decision-making with sustainability metrics and policy instruments. Moreover, the network highlights the need for global collaboration and renewable energy-based innovations to foster low-carbon, resilient, and intelligent cold chain systems aligned with the Sustainable Development Goals (SDGs).

Critical insights into cold chain logistics research are illustrated in the Figure 6. Part (a) demonstrates journal interconnectivity and citation impact, emphasizing the relationships and

influence among prominent academic journals, while part (b) presents a co-citation network of influential authors, highlighting the collaborative and referenced studies that are shaping the field.

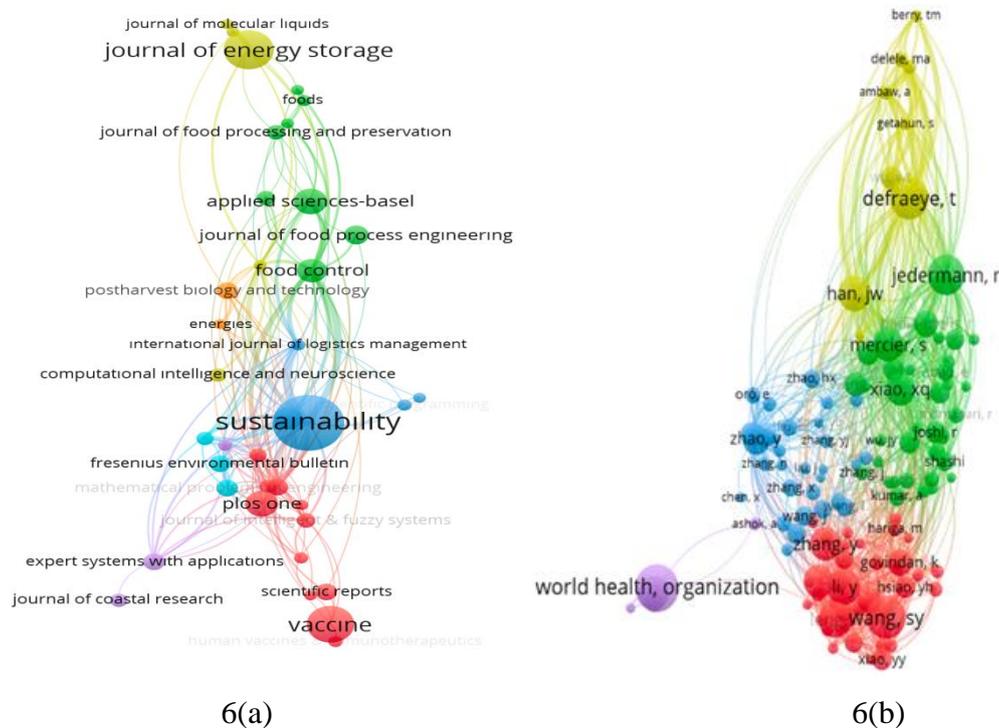


Figure 6. Citation Network Mapping of Journals and Co-citation Network Mapping of Authors

The journal interconnectivity within cold chain logistics research, as revealed through citation mapping, highlights the interdisciplinary nature of the field, with quantitative insights demonstrating the strength of these connections (see Figure 6(a)). *The Journal of Sustainability* leads the field, with 40 documents and 497 citations, achieving a total link strength of 80, underscoring its central role in bridging environmental sustainability with logistics practices. Similarly, *the Journal of Food Control* contributes 14 documents and 737 citations, with a link strength of 74, emphasizing its significant influence in connecting food safety with cold chain logistics. Journals such as the *Journal of Energy Storage*, with 26 documents, 442 citations, and a link strength of 14, reflect strong associations with sustainability and technological innovation, highlighting the integration of energy-efficient solutions in cold chain logistics.

This numerical data sheds light on the patterns of collaboration and citation among journals across diverse fields such as logistics management, energy systems, and sustainability, highlighting the interdisciplinary nature of cold chain logistics research. The

substantial link strengths and high citation counts reflect a robust exchange of knowledge, supporting the collective effort to address challenges such as reducing carbon emissions, optimizing supply chains, and enhancing vaccine distribution. These interconnections not only promote interdisciplinary collaboration but also drive innovation in solving global logistical challenges by integrating environmental, technological, and operational insights.

The co-citation network mapping illustrated in Figure 6(b) underscores the interdisciplinary nature of cold chain logistics research. Notably, the World Health Organization (WHO) emerges as a central node, with 122 citations and a link strength of 218, reflecting its pivotal role in global health logistics, vaccine distribution, and operational innovations frequently referenced by leading scholars.

Similarly, Defraeye et al., (2015), with 109 citations and an impressive link strength of 1304, focuses on optimizing cold chain operations, particularly in minimizing food waste and enhancing energy efficiency in the transportation of perishable goods. Their research serves as a key bridge between logistics efficiency and sustainability. This interconnectedness promotes collaborative solutions to critical challenges such as vaccine distribution, food security, and environmental sustainability, positioning cold chain logistics as a multidisciplinary field essential for addressing global issues.

5. Discussion and Conclusion

This article presents a bibliometric analysis of cold chain logistics, exploring its advancements by mapping key authors, countries, and their alignment with global sustainability goals. It also identifies critical research gaps and proposes future directions to improve the efficiency and impact of the field.

This study, while providing valuable insights into cold chain logistics research, has several limitations. First, the bibliometric analysis relies exclusively on data from the WoS database, which may exclude pertinent studies indexed in other databases such as Scopus or PubMed, thereby potentially limiting the comprehensiveness of the findings. Second, the study primarily emphasizes quantitative metrics, including citation counts and link strengths, which may overlook qualitative dimensions of research impact, such as practical applications and societal benefits. Moreover, the analysis is constrained by a predefined time frame and threshold parameters, which may exclude emerging authors and recent studies with lower citation counts. Another limitation is the geographic bias inherent in cold chain research, with a predominant focus on developed regions, potentially underrepresenting contributions from developing countries where cold chain challenges are more acute. Finally, although the study

highlights key research gaps, it does not propose specific solutions or frameworks to address these challenges, thereby offering opportunities for further investigation in future research.

The analysis of the most cited studies presented in Table 1 provides critical insights into the intellectual evolution of cold chain logistics research and its interdisciplinary expansion. These highly influential publications collectively reflect two dominant research trajectories: (i) the enhancement of temperature-controlled systems for pharmaceuticals and vaccines, and (ii) the development of sustainable and efficient logistics frameworks for food and agricultural products. For example, Wang et al. (2020) and Tan et al. (2021) addressed the operational and technological challenges of vaccine storage and distribution during the COVID-19 pandemic, contributing to the advancement of health-oriented cold chain systems. Meanwhile, Porat et al. (2018) and Kuo and Chen (2010) emphasized the reduction of postharvest food losses and optimization of supply chain efficiency through innovations such as the Multi-Temperature Joint Distribution (MTJD) model. Methodologically, Singh et al. (2018) introduced a hybrid fuzzy decision-making framework for third-party logistics selection, while Chianella et al. (2013) explored nanotechnology-based detection systems to improve quality monitoring in temperature-controlled environments. Collectively, these studies shaped the thematic and methodological direction of the field by integrating technological innovation, sustainability assessment, and public health logistics. Their influence underscores a paradigm shift from traditional, operationally focused research toward data-driven, resilient, and sustainability-oriented approaches, highlighting the growing role of digitalization, decarbonization, and multidisciplinary collaboration in the evolution of global cold chain logistics.

Key research gaps in cold chain logistics highlight the need for further advancements in sustainability, technology integration, and equitable access. While progress has been made in reducing carbon emissions and enhancing energy efficiency, research on the integration of renewable energy sources, such as solar power, remains limited. Technological innovations such as IoT, blockchain, and Artificial Intelligence (AI) demonstrate considerable potential, yet face challenges related to scalability and cost, particularly in developing regions. Despite the momentum gained in vaccine logistics research during the COVID-19 pandemic, significant gaps persist in addressing the logistics of other essential pharmaceuticals in underserved areas. Similarly, although food waste reduction has been extensively studied in transportation and storage, inefficiencies at the retail and consumer levels remain largely underexplored. Moreover, there is a notable lack of focus on harmonizing international policies and regulatory frameworks to ensure the consistency of cold chain standards across

borders. Addressing these gaps is crucial for advancing sustainability, enhancing operational efficiency, and achieving global health and food security objectives.

The findings of this study underscore several policy implications critical for enhancing the effectiveness and sustainability of cold chain logistics systems. Policymakers should prioritize the development of harmonized international standards to ensure consistent protocols for temperature-sensitive goods, thus facilitating more efficient cross-border trade and global supply chain operations. Furthermore, investments in renewable energy technologies, such as solar-powered refrigeration, should be incentivized through subsidies and grants to reduce the environmental impact of cold chain systems and align with global climate action objectives.

In addition, governments and international organizations, including the WHO, should establish and enforce regulatory frameworks to ensure equitable access to vaccines, perishable goods, and other essential supplies, particularly in underserved regions. In contrast to previous bibliometric studies that predominantly focused on specific sub-domains—such as sustainability issues in perishable goods (Vrat et al., 2018), regional analyses limited to China (Kang et al., 2021), or sector-specific applications such as seafood logistics (Hu et al., 2024)—the present research offers a holistic and integrative examination of cold chain logistics over a 15-year period. By incorporating 911 publications from 2010 to 2024 and applying co-citation, keyword, and country mapping analyses, this study provides a broader and more systematic understanding of the field's evolution. Unlike prior works that primarily emphasized publication trends or network visualization, our analysis contextualizes these bibliometric patterns within theoretical, practical, and policy frameworks, linking them to global sustainability goals, digital transformation, and post-pandemic supply chain resilience. Thus, the study not only bridges fragmented research perspectives but also establishes a comprehensive reference point for future investigations into the interdisciplinary development of cold chain logistics.

Furthermore, the integration of digital technologies such as the IoT, blockchain, and AI into policy frameworks can significantly enhance traceability, reduce waste, and improve supply chain efficiency. Policies that promote public-private partnerships can stimulate innovation and foster collaboration among academia, industry, and government stakeholders to address complex logistical challenges. Additionally, capacity-building initiatives, including workforce training and educational programs, are vital for equipping personnel with the necessary skills to manage advanced cold chain systems effectively. By addressing these policy areas, governments and organizations can establish more sustainable, resilient, and

equitable cold chain logistics systems that support global health, food security, and environmental sustainability.

Enhancing cold chain logistics necessitates interdisciplinary approaches that integrate technology, sustainability, and collaboration. The adoption of technologies such as IoT sensors, blockchain, and AI can optimize temperature monitoring, traceability, and route planning, while renewable energy solutions, such as solar-powered cooling systems, help reduce carbon emissions and improve energy efficiency. Collaborative efforts between academia, industry, and international organizations, such as the WHO, are essential for standardizing practices and aligning cold chain systems with global health and sustainability objectives. Data-driven approaches, including big data analytics and digital twins, further enhance supply chain efficiency and resilience. Additionally, policy harmonization and workforce training programs are critical to addressing regulatory challenges and equipping professionals with the necessary skills to manage advanced cold chain systems. These interdisciplinary strategies collectively contribute to the sustainability, efficiency, and global impact of cold chain logistics.

Future research in cold chain logistics should adopt innovative methodological approaches to address pressing global challenges in food security, healthcare, and sustainability. Emphasis should be placed on leveraging big data analytics and machine learning algorithms to predict demand, optimize routing, and enhance real-time monitoring. Blockchain integration methodologies can strengthen traceability and transparency, while digital twin models offer the ability to simulate cold chain operations, allowing for the evaluation and improvement of system performance under various scenarios. In this context, scenario analysis as well as modeling and simulation techniques—such as discrete-event simulation, system dynamics, and agent-based modeling—can be utilized. Research should also prioritize life cycle assessments (LCA) and carbon footprint analyses to foster the development of environmentally sustainable practices. In this context, environmental impact analysis, input-output analysis, and quantitative comparative analysis (e.g., comparison of carbon footprints associated with different transportation modes) can be conducted. Furthermore, mixed-method approaches, combining quantitative tools such as network analysis with qualitative insights from stakeholder interviews and field studies, can provide a more comprehensive understanding of the challenges within cold chain logistics. Interdisciplinary collaborations should focus on designing scalable models for renewable energy integration and developing standardized frameworks to harmonize policies and operations on a global scale. Although the present study does not include an in-depth theoretical analysis, the patterns identified in the

bibliometric results point to several promising theoretical directions—such as sustainability transitions, resilience theory, and risk governance—that can be examined in greater detail in future research.

To this end, optimization models such as linear programming and multi-criteria decision-making, energy modeling tools such as HOMER and RETScreen, as well as simulation modeling and scenario-based analysis, can be employed. In addition, policy analysis, the Delphi method—to incorporate expert perspectives in developing a framework—decision analysis and multi-criteria decision-making methods for evaluating policy alternatives, as well as a scientific design approach for establishing a standardized framework and its validation, can be utilized.

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