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MAPPING BLOCKCHAIN'S IMPACT ON COLD CHAIN LOGISTICS: INSIGHTS FROM BIBLIOMETRIC AND CO-CITATION ANALYSIS

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ABSTRACT

Blockchain technology has emerged as a transformative solution for enhancing transparency, traceability, and operational efficiency in cold chain logistics, particularly for temperature-sensitive goods. However, despite its growing importance, a comprehensive understanding of its application in this domain remains limited. This study aims to map the academic literature on blockchain in cold chain logistics by conducting bibliometric and co-citation analyses of 112 papers retrieved from Scopus and Web of Science databases. For these analyses, the Biblioshiny and Bibliometrix libraries, tools for comprehensive science mapping analysis, were utilized within R Studio. The analysis explores publication trends, thematic evolution, and collaboration networks, offering a structured overview of the current research landscape. Key findings reveal a surge in publications during the COVID-19 pandemic, driven by the need for reliable vaccine distribution systems. Dominant themes include the integration of blockchain with Internet of Things (IoT), machine learning, and traceability systems, reflecting technological advancements in real-time monitoring and predictive analytics. Collaboration analysis identifies China and Canada as leading contributors, though regional disparities in research activity persist. This study contributes to the literature by identifying research gaps, such as the scalability and cost-effectiveness of blockchain in cold chain logistics, and by proposing actionable insights for future studies. It highlights opportunities for cross-disciplinary research and emphasizes the importance of standardizing blockchain frameworks for global adoption. For practitioners, the findings underscore the potential of blockchain to optimize supply chains and reduce losses in critical sectors like healthcare and food logistics. This paper serves as a reference for academics and industry stakeholders, providing a foundation for advancing research and practical applications in this evolving field.

Keywords: *Cold Chain Logistics, Blockchain, Bibliometric Analysis, Co-citation Analysis.*

1. INTRODUCTION

The rapid globalization and growing interconnectivity of supply chains have significantly enhanced the efficiency and reach of modern logistics systems. However, these advancements have also introduced greater complexity and susceptibility to disruptions, particularly in cold chain logistics, which are essential for transporting temperature-sensitive goods such as vaccines, pharmaceuticals, and perishable foods. Inadequate management of temperature-controlled logistics systems can result in severe economic losses, public health crises, and sustainability challenges. For instance, disruptions in cold chain systems during the COVID-19 pandemic underscored the need for enhanced transparency, accountability, and traceability in global supply chains. The pandemic revealed weaknesses in existing cold chain logistics infrastructure, highlighting an urgent need for technologies that can provide real-time monitoring, improved data integrity, and operational efficiency (Halim et al., 2021; Jiang et al., 2024).

In response to these challenges, blockchain technology has emerged as a revolutionary solution to address critical issues in cold chain logistics. Introduced in the 2008 white paper *Bitcoin: A Peer-to-Peer Electronic Cash System* by Satoshi Nakamoto, blockchain has revolutionized industries by offering decentralized, immutable, and secure data-sharing capabilities (Hofmann et al., 2017; Lal, 2020). Unlike traditional systems that rely on centralized intermediaries prone to inefficiencies and inaccuracies, blockchain enables transparent and tamper-proof data sharing across stakeholders. This

is particularly important for cold chains, where deviations from required temperature ranges can compromise product quality and safety. Blockchain, when combined with complementary technologies like the Internet of Things (IoT), machine learning, and artificial intelligence, offers immense potential to enhance the traceability, reliability, and sustainability of cold chain systems (Cil et al., 2022; Rejeb et al., 2022).

The significance of blockchain in cold chain logistics is underscored by its ability to address challenges related to transparency, traceability, and operational inefficiency. For instance, IoT-enabled blockchain systems allow stakeholders to monitor real-time temperature, location, and handling conditions, preventing spoilage and enhancing supply chain resilience (Shashi et al., 2018; Hu, 2022). By securely recording every transaction and process step, blockchain provides an immutable record of goods' journeys, improving accountability. This is especially crucial in critical sectors like healthcare and food logistics, where product integrity is paramount (Nofer et al., 2017; Bamakan et al., 2021).

Despite the promising potential of blockchain technology, its adoption in cold chain logistics remains in its early stages. The academic literature on this topic is fragmented, with limited interdisciplinary studies exploring its full applications. Research on blockchain in broader supply chain management is extensive, but specific studies on cold chains are relatively few (Rejeb et al., 2022). This gap highlights the need for a comprehensive synthesis of existing knowledge to inform both researchers and practitioners. Such an effort would identify current trends, dominant themes, and gaps while pointing to future opportunities for blockchain implementation (Masudin et al., 2021; Zhang et al., 2022).

The COVID-19 pandemic further amplified the need for robust cold chain systems and accelerated the adoption of blockchain in logistics. From 2020 to 2022, there was a marked increase in academic research exploring blockchain's applications in cold chains, particularly for vaccine distribution (Mustafa et al., 2024). This period saw the emergence of new research themes, such as the integration of blockchain with IoT, machine learning, and cryptographic systems, which collectively improve real-time monitoring and efficiency (Sunny et al., 2020). However, challenges remain, including scalability issues, high implementation costs, and regulatory barriers that limit blockchain's widespread adoption, particularly among small and medium-sized enterprises (Mustafa et al., 2024; Ramírez et al., 2022).

Bibliometric analysis offers a powerful method to synthesize the growing body of literature on blockchain in cold chain logistics. It allows for the identification of key trends, influential studies, and collaborative networks within a research domain (Aria & Cuccurullo, 2017; Rejeb, 2022). Co-citation analysis further enables the mapping of intellectual foundations and emerging themes by examining relationships between cited works. These tools are particularly valuable for evaluating blockchain research, which spans diverse disciplines such as computer science, logistics, and sustainability (Cil et al., 2022; Shen et al., 2022).

To address the fragmented state of the literature, this study employs bibliometric and co-citation analyses to map the intellectual landscape of blockchain research in cold chain logistics. A total of 112 peer-reviewed papers were retrieved from Scopus and Web of Science, two leading academic databases known for their comprehensive coverage and reliability. These analyses were conducted using the *Biblioshiny* and *Bibliometrix* libraries within R Studio, tools widely recognized for their robustness in science mapping (Aria & Cuccurullo, 2017). The research focuses on identifying publication trends, thematic areas, and collaboration networks to provide a structured overview of this evolving field.

The objectives of this study are threefold. First, it aims to provide a comprehensive overview of the research landscape by analyzing publication trends, authorship patterns, and institutional collaborations. Second, it seeks to identify thematic areas and emerging trends in blockchain applications for cold chain logistics. Third, it highlights research gaps and proposes future research directions to advance the

field. By addressing these objectives, this study contributes to both theory and practice. It offers valuable insights for academics seeking to build upon existing knowledge and actionable guidance for industry stakeholders exploring blockchain adoption in cold chain systems.

The findings of this study are expected to contribute significantly to both academia and industry. For researchers, the results provide a comprehensive synthesis of the current state of knowledge, highlighting areas for future inquiry and interdisciplinary collaboration. For practitioners, the insights offer actionable guidance on leveraging blockchain to enhance cold chain operations, improve traceability, and ensure product quality. Policymakers will also benefit from these findings, which emphasize the need for standardized protocols and incentives to promote blockchain adoption in critical sectors (Halim et al., 2021; Shen et al., 2022).

This paper is structured as follows: After the introduction, the methodology section describes the bibliometric and co-citation analysis methods used in this study, along with the data collection process. The results section presents key findings, including publication trends, collaboration networks, and thematic areas. The discussion section critically interprets these findings, highlighting their implications for theory and practice. Finally, the conclusion summarizes the study's contributions, discusses its limitations, and offers recommendations for future research.

By synthesizing the current knowledge base and offering actionable recommendations, this study aims to bridge the gap between theory and practice, fostering innovation and sustainability in cold chain logistics. Blockchain technology's transformative potential positions it as a cornerstone of resilient and transparent supply chains, capable of meeting the demands of an increasingly interconnected and sustainability-focused world.

2. BACKGROUND

The rapid expansion of global supply chains has brought with it new challenges, particularly in industries reliant on the integrity of temperature-sensitive goods, such as pharmaceuticals, food products, and medical supplies. Cold chain logistics has become critical for these sectors, ensuring that products are transported, stored, and delivered under specific temperature conditions to maintain their quality and safety. However, traditional cold chain systems are often inefficient, prone to disruptions, and vulnerable to fraud. The increasing demand for transparency, traceability, and sustainability within these systems has driven the exploration of new technologies, with blockchain emerging as one of the most promising solutions.

In a recent study, Mustafa et al. (2024) conducted a bibliometric analysis of 114 academic publications in the field of Food Cold Chain Logistics and Management (FCCLM). Their research highlights the growing importance of sustainability and technological advancements such as radio frequency identification (RFID) and the Internet of Things (IoT) in optimizing cold chain systems. The study identifies six principal research clusters, revealing the diverse ways in which emerging technologies are transforming the sector. However, Mustafa et al. (2024) also point out several key gaps in the existing literature, including the lack of research on human factors in food cold chain logistics and the impact of climate change. These gaps represent areas of significant concern and opportunities for further research.

Blockchain technology, a decentralized, immutable, and secure digital ledger, has gained considerable attention for its potential to address these shortcomings in cold chain logistics. Blockchain provides a transparent, real-time, and verifiable way of tracking and managing transactions throughout the supply chain. Haoran (2024) explores the application of blockchain technology in cold chain finance to resolve information asymmetry and trust issues, which are inherent in traditional cold chain logistics finance models. By implementing blockchain, cold chain logistics can benefit from enhanced trust and real-time data validation, ensuring that transactions are not tampered with or delayed. Haoran (2024) uses empirical case studies to substantiate the potential of blockchain to streamline

operations, improve data integrity, and reduce the risk of fraud.

In addition to addressing financial and trust-related challenges, blockchain technology also has significant potential to resolve structural issues in cold chain logistics systems. Zhang et al. (2023) propose a blockchain-based model designed to mitigate the centralization issues that are commonly found in traditional cold chain logistics systems (CCLS). These centralized systems often suffer from inefficiencies in data access, validation, and pricing. Blockchain offers a decentralized solution that ensures data immutability and traceability, providing greater security, efficiency, and cost-effectiveness. Zhang et al. (2023) optimize this model through the application of Stackelberg game theory, which improves the allocation of data resources in the system. This integration of blockchain with game theory aims to create a more secure, efficient, and economical logistics system, with better resource distribution and minimized operational risks.

In agricultural cold chain logistics, Si (2022) presents a private blockchain system that addresses challenges related to the storage and authorization of transactions within the blockchain framework. This system enables controllable sharing and transactions of data while ensuring secure access and management. Si (2022) highlights the efficiency of blockchain in agricultural cold chain logistics, where the analysis of data between 2017 and 2021 reveals high efficiency (above 0.9). However, Si (2022) suggests that improvements can be made both at the technical and management levels of agricultural cold chain logistics. The need for better integration, more robust systems, and standardized protocols is evident as the agricultural sector seeks to reduce waste and improve the efficiency of cold chain operations.

Pharmaceutical cold chains also stand to benefit significantly from blockchain technology. Bamakan et al. (2021) take a comprehensive approach to exploring how blockchain can address the specific challenges of the pharmaceutical cold chain, which often deals with highly regulated, temperature-sensitive products. The authors analyze five case studies to demonstrate how blockchain can meet critical requirements, such as digital identification of medicines, serialization, traceability, data integrity, transparency, and waste management. Despite these advantages, Bamakan et al. (2021) acknowledge several limitations of blockchain in pharmaceutical chains, including issues related to regulatory compliance, high implementation costs, and scalability concerns. These limitations suggest that while blockchain has great potential, further research and development are necessary to optimize its application in pharmaceutical logistics.

The broader implications of blockchain for supply chain management are examined in a bibliometric review by Rejeb et al. (2021). Their analysis of 628 papers published between 2016 and 2020 reveals a significant increase in blockchain-related research, particularly since 2017. The review identifies key areas of focus, such as blockchain's role in sustainability, the barriers to its adoption, and the security challenges in supply chains. Rejeb et al. (2021) also highlight the leading countries in blockchain research—namely the United States, China, and India—which are at the forefront of both technological innovation and academic research in the field. Despite the growing body of literature, Rejeb et al. (2021) point out the gaps in understanding the full potential of blockchain, particularly regarding the integration of blockchain into complex, global supply chains and the legal, economic, and technological challenges that come with such integration. These findings underscore the need for more comprehensive studies that explore blockchain's application across various sectors and its long-term impact on supply chain management.

Blockchain's application is also evident in healthcare logistics, where it has the potential to optimize blood supply chains. Kim & Kim (2018) propose a novel blockchain-based system designed to address the limitations of existing centralized blood management systems. The authors point out that traditional systems are often slow to provide real-time data, particularly in emergency situations, where the need for immediate access to information is critical. The proposed blockchain system offers a more efficient and transparent approach to blood logistics, improving the speed of response during

emergencies and ensuring that blood supplies are maintained at the correct temperature. This example demonstrates blockchain's potential not only in traditional cold chain logistics but also in critical healthcare supply chains, where data integrity and timely access are essential for saving lives.

Together, these studies highlight the significant potential of blockchain technology in transforming cold chain logistics across various sectors. The ability to provide transparency, traceability, and real-time data validation offers immense benefits, particularly in sectors where the integrity of goods is paramount, such as pharmaceuticals, food safety, and healthcare. However, as highlighted by multiple studies, the integration of blockchain into existing cold chain systems is not without its challenges. Issues such as scalability, high implementation costs, and regulatory compliance need to be addressed before blockchain can be adopted on a large scale.

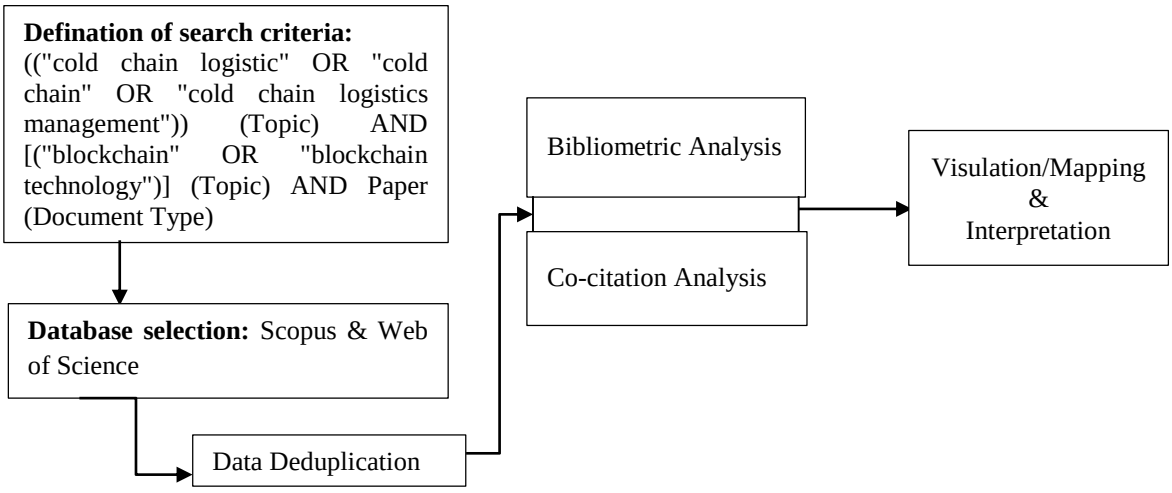
The research also reveals that the current body of literature is fragmented, with a lack of comprehensive studies that examine the broader implications of blockchain adoption across various cold chain sectors. While the technology has demonstrated success in specific case studies, further research is needed to explore how blockchain can be effectively integrated into complex, global supply chains, particularly in resource-constrained environments. Furthermore, the human factors involved in blockchain adoption, such as workforce training and user acceptance, have received limited attention in the literature (Mustafa et al., 2024). These gaps represent significant opportunities for future research, particularly in understanding the challenges and opportunities of blockchain technology from both a technological and human-centric perspective.

Overall, while blockchain holds significant promise for revolutionizing cold chain logistics, there is still much work to be done to fully realize its potential. The integration of blockchain with other emerging technologies such as IoT, machine learning, and artificial intelligence could further enhance its capabilities, creating smart cold chains that proactively manage risks and optimize operations. As the field continues to evolve, it will be essential for researchers, practitioners, and policymakers to collaborate to address the barriers to blockchain adoption and to ensure that the technology can deliver its full benefits in the complex and ever-evolving world of cold chain logistics.

3. DATA AND METHODOLOGY

This study aims to identify trends, thematic areas, and future directions in research on blockchain applications in cold chain logistics, as reflected in papers published in the Scopus and Web of Science (WOS) databases. The analysis process is depicted in Figure 1.

Figure 1. Research Analysis Process (Source: Authors' Drawing)



The initial step involved defining the search criteria to ensure a comprehensive collection of relevant data. The search terms were structured as follows: ("cold chain logistic" OR "cold chain" OR "cold chain logistics management") (Topic) AND [("blockchain" OR "blockchain technology")] (Topic) AND Paper (Document Type). These terms encompassed key topics related to both cold chain logistics and blockchain technology. The search was restricted to papers and carried out using subject headings in both databases.

Two prominent academic databases, Scopus and WOS, were selected to ensure robust and reliable data retrieval. The search yielded 105 papers from Scopus and an additional 41 papers from WOS. After combining the datasets, duplicate entries were identified and removed, resulting in a final dataset of 112 unique papers.

Following data consolidation, two analytical methods were applied to the cleaned dataset: bibliometric analysis and co-citation analysis. The use of bibliometric analysis as a research method has increased significantly in the social sciences in recent years (Başdeğirmen, 2023). The bibliometric analysis method enables researchers to make comparisons between countries, institutions or years on a range of subjects. The underlying assumption of co-citation analysis is that two documents are more likely to be related when they refer to the same author, publication or journal together (Rejeb, 2022).

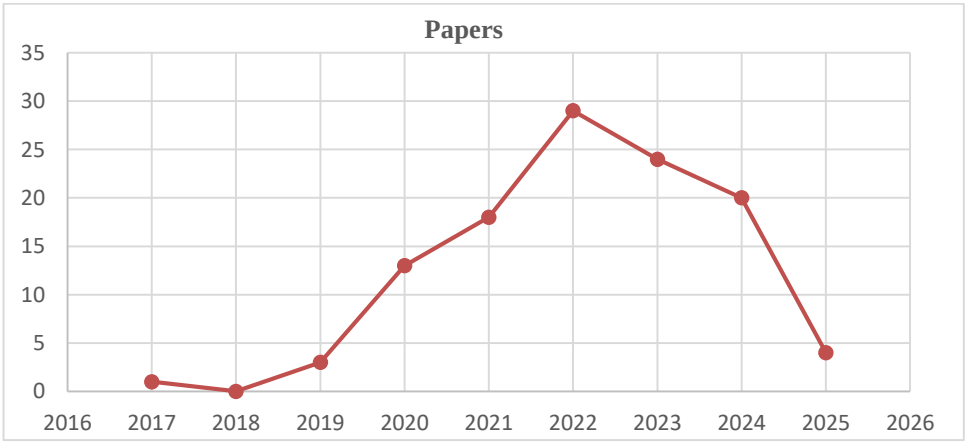
4. DATA ANALYSIS AND VISULATION

This section presents the findings of the bibliometric and co-citation analyses conducted on the paper. The findings from these analyses were visually represented and interpreted. The visualization and mapping phase aimed to clearly illustrate the structure and focal points of blockchain-related academic literature in cold chain logistics, providing insights into key trends and research themes.

Publication Trends

The annual publication trends, illustrated in **Figure** 2, show a significant growth in academic interest in blockchain applications for cold chain logistics. From a single publication in 2017, the field saw a steady rise, culminating in 29 papers published in 2022. This upward trajectory highlights the increasing recognition of blockchain's potential in addressing logistical challenges, particularly in response to the COVID-19 pandemic. Notably, the pandemic spurred research due to the critical need for reliable vaccine distribution systems. However, a slight decline in publications occurred in 2023 and 2024, with 24 and 20 papers respectively. Despite this dip, the consistent output indicates sustained interest, and projections suggest a potential resurgence in 2025 as global recovery processes progress.

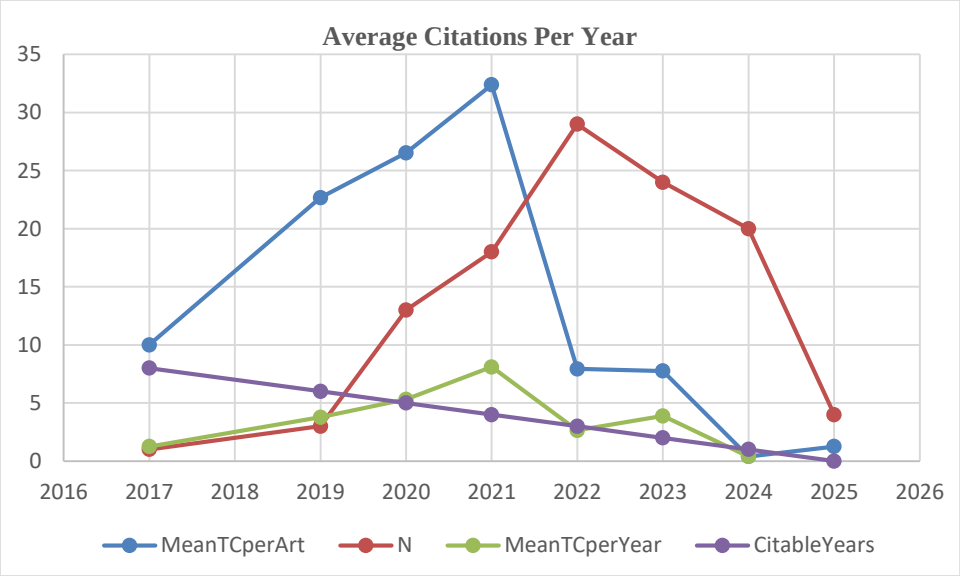
Figure 2. Annual Scientific Production



Citation Analysis

Figure 3 provides insights into the citation patterns of the analyzed papers. The highest average citation per paper was observed in 2021, with a mean of 32.39 citations, underscoring the impact of research published during this period. This peak reflects the growing relevance of blockchain technologies in critical logistics operations during the pandemic. Although citation density declined after 2022, this trend may be attributed to the increasing number of new publications diluting average citations. Nevertheless, the substantial citation counts highlight the enduring significance of this research area.

Figure 3. Avarage Citation Per Year of Sample Papers



*TC : Total Citation

Source: Authors' own drawing

Most Relevant Sources

Table 1 lists the top ten sources where papers were published. The "ACM International Conference Proceeding Series" leads with four papers, indicating the prominence of conference proceedings in disseminating cutting-edge findings. Journals like "CMC-Computers Materials & Continua" and "Computational Intelligence and Neuroscience" each contributed three papers, showcasing the interdisciplinary nature of the research. Additionally, the presence of sources like "Frontiers in Sustainable Food Systems" emphasizes the practical implications of blockchain in enhancing food logistics and sustainability.

Table 1. Top Ten of the Most Relevant Sources among Sample Papers

	Sources	Papers
1	ACM International Conference Proceeding Series	4
2	CMC-Computers Materials \& Continua	3
3	Computational Intelligence and Neuroscience	3
4	Lecture Notes in Networks and Systems	3
5	5th International Conference on Universal Village, UV 2020	2
6	Communications In Computer and Information Science	2
7	Expert Systems with Applications	2
8	Food And Machinery	2
9	Frontiers In Sustainable Food Systems	2
10	Heliyon	2

Most Influential Sources

Table 2 highlights the most impactful sources, ranked by metrics such as h-index and total citations. "Journal of Cleaner Production" stands out with 152 citations, reflecting its influence in promoting sustainable practices. Similarly, "Expert Systems with

Applications" and "Heliyon" are notable contributors, with their focus on advanced technologies and practical applications in logistics. These sources underscore the cross-disciplinary appeal of blockchain research, blending insights from technology, logistics, and environmental sustainability.

Table 2. Top Ten of the Most Impactful Sources among Sample Papers

Element	h_index	TC	NP	PY_start
Computational Intelligence and Neuroscience	2	21	3	2022
Expert Systems with Applications	2	49	2	2021
Food And Machinery	2	9	2	2021
Heliyon	2	29	2	2023
Journal Of Cleaner Production	2	152	2	2021
2019 IFIP/IEEE Symposium on Integrated Network and Service Management, IM2019	1	24	1	2019
2020 11th International Conference on Computing, Communication and Networking Technologies, ICCCNT 2020	1	14	1	2020
2020 IEEE International Conference on Pervasive Computing and Communications Workshops, Percom Workshops 2020	1	12	1	2020
2023 International Conference on Intelligent Computing, Communication, Networking and Services, ICCNS2023	1	2	1	2023
2nd IEEE International Conference on Distributed Computing And Electrical Circuits And Electronics, ICDCECE 2023	1	2	1	2023

Most Impactful Documents

Table 3 identifies the top ten globally cited papers, with "Sunny et al. (2020)" leading at 241 citations. This paper's significant impact stems from its focus on blockchain's role in enhancing supply chain transparency. The second-ranked paper by "Han et al. (2021)" and others in the list demonstrate the diversity of blockchain applications across sectors like food safety, pharmaceuticals, and logistics. These influential works provide foundational knowledge and inspire subsequent studies in the field.

Table 3. Top Ten Globally Cited Documents among Sample Papers

Paper	DOI	Total Citations
Sunny et al., 2020, Comput Ind Eng	10.1016/j.cie.2020.106895	241
Han et al., 2021, Trends Food Sci Technol	10.1016/j.tifs.2021.01.066	190
Bamakan et al., 2021, J Clean Prod	10.1016/j.jclepro.2021.127021	132
Baralla et al., 2021, Concurr Comput-Pract Exp	10.1002/cpe.5857	68
Masudin et al., 2021, Global J Flexible Syst Manage	10.1007/s40171-021-00281-x	50
Qian et al., 2022, Food Control	10.1016/j.foodcont.2022.108940	40
Yan et al., 2020, Proc Acm Sigmod Int Conf Manage Data	10.1145/3318464.3386127	40
Yadav & Kumar, 2023, Int J Prod Econ	10.1016/j.ijpe.2022.108716	39
Badhotiya et al., 2021, Mater Today Proc	10.1016/j.matpr.2021.01.673	38
Singh et al., 2023, Multimed Tools Appl	10.1007/s11042-022-14006-4	35

Social Structure and Collaboration Networks

One of the defining characteristics of scientific research is the extent to which it is conducted in collaboration with researchers in other countries (Matveeva et al., 2022). The nature of scientific research is evolving in such a way that it is becoming increasingly collaborative. The application of bibliometric techniques represents an efficacious and unobtrusive methodology for the analysis and comprehension of collaboration within the domain of scientific research (Subramanyam, 1983). Table 4 and Figure 4 demonstrate the prevalence of international collaboration as evidenced by a sample of papers.

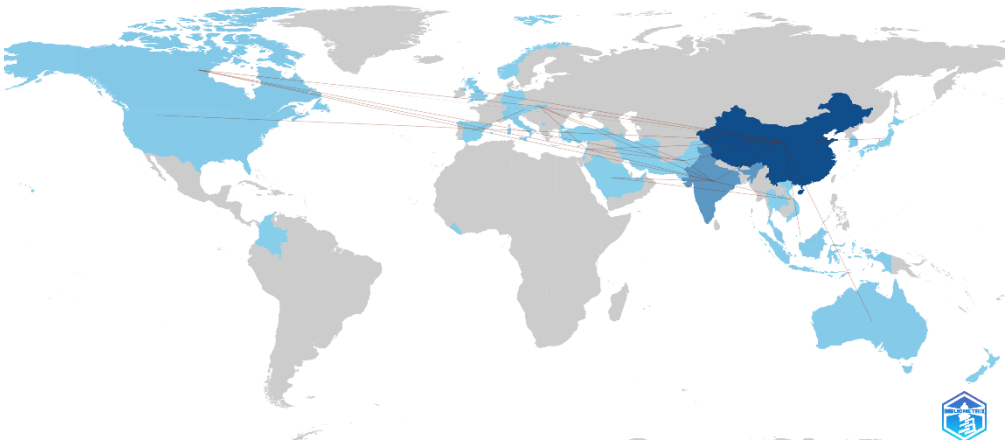
Collaboration networks, detailed in **Table 4** and visualized in **Figure 4**, reveal the central role of China and Canada in advancing blockchain research in cold chain logistics. China's frequent collaborations, particularly with Canada, underscore its leadership in technological innovation. Meanwhile, Canada's

diverse partnerships with countries like Slovakia, Pakistan, and Lebanon highlight its active role in fostering global academic cooperation. Such collaborations are essential for addressing regional disparities and promoting inclusive advancements in cold chain logistics.

Table 4. Collaboration Networks between Countries in Sample Papers

From	To	Frequency	From	To	Frequency
Canada	Lebanon	1	China	Usa	1
Canada	Pakistan	1	India	Canada	1
Canada	Slovakia	1	India	Lebanon	1
China	Australia	1	India	Pakistan	1
China	Canada	3	India	Saudi Arabia	1
China	India	1	India	Slovakia	1
China	Japan	1	India	Vietnam	1
China	Lebanon	1	Lebanon	Pakistan	1
China	Malaysia	1	Lebanon	Slovakia	1
China	Pakistan	1	Pakistan	Slovakia	1
China	Slovakia	1	Saudi Arabia	Vietnam	1
China	United Kingdom	1	Spain	Austria	1

Figure 4. Countries' Collaboration World Map



Country Citation Rankings

Table 5 ranks countries based on total and average citations per paper. China leads with 437 total citations, reflecting its extensive research output and influence. Interestingly, Iran achieves the highest average citations per paper at 132, indicating the exceptional impact of its contributions despite a lower publication volume. These metrics underscore the global nature of blockchain research and the varying levels of academic impact across regions.

Table 5. Citation Rankings of Leading Countries

Country	Total Citation	Average Paper Citations
China	437	10.40
India	364	26.00
Iran	132	132.00
Italy	68	68.00
Indonesia	58	29.00
Korea	49	12.20
Vietnam	35	35.00
U Arab Emirates	26	26.00
Spain	19	19.00
Germany	18	18.00
United Kingdom	14	14.00
Lebanon	12	12.00
Israel	9	9.00
Singapore	9	9.00

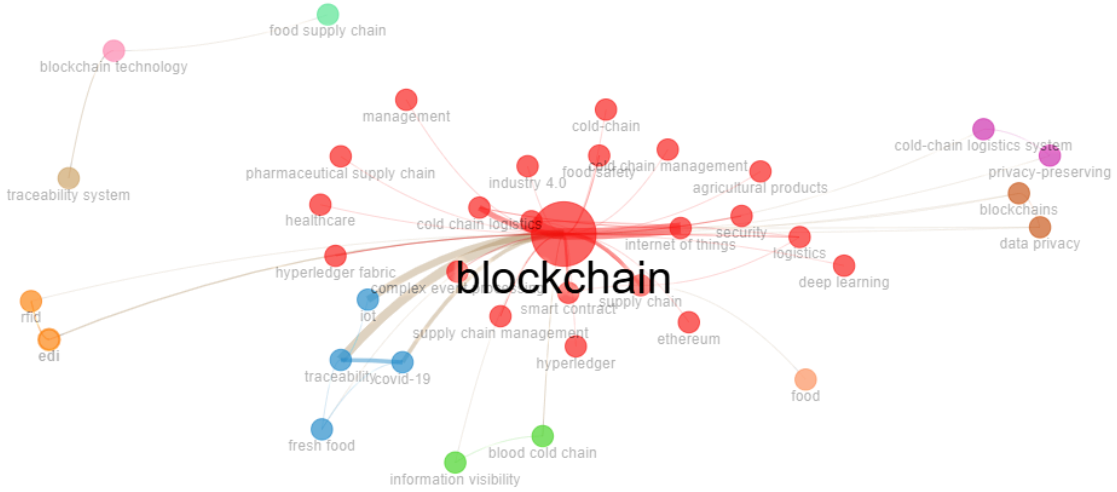
Colombia	8	8.00
Turkey	4	4.00
Brunei	2	2.00
Australia	1	1.00
Slovakia	1	1.00

Co-occurrence Analysis

The co-word occurrence maps, created using different terms, demonstrate the evolution of research keywords in the SSCM field. Moreover, the map demonstrates the evolution and persistence of concepts that are relevant to the field. The co-occurrence analysis enables researchers to monitor the activities of actors in an impartial manner and to ascertain the dynamics of scientific progress in all its aspects (Sedighi, 2016; Özcan Akdağ & Tunca, 2022).

The co-occurrence network, illustrated in **Figure** 5, highlights key terms frequently associated with blockchain in cold chain logistics. Central terms like "blockchain," "cold chain," and "Internet of Things" demonstrate the integration of advanced technologies in logistics systems. Emerging themes such as "smart contracts," "traceability," and "machine learning" reflect the evolving focus on automation and predictive analytics. Moreover, additional keywords such as cold chain logistics, smart contract, food safety, logistics, security, agricultural products, cold-chain, Ethereum, Hyperledger Fabric, management, pharmaceutical supply chain, supply chain management, cold chain management, complex event processing, deep learning, healthcare, Hyperledger, Industry 4.0, and traceability are also frequently used. Moreover, terms such as "COVID-19," "IoT," "fresh food," "blood cold chain," "information visibility," "cold-chain logistics system," "privacy-preserving," "edi," "rfid," "blockchains," "data privacy," "blockchain technology," "traceability system," "food supply chain," and "food" are of particular significance within the studies. The dense network of related terms indicates a robust and interconnected research landscape.

Figure 5. Co-occurrence Network Analysis among Sample Papers



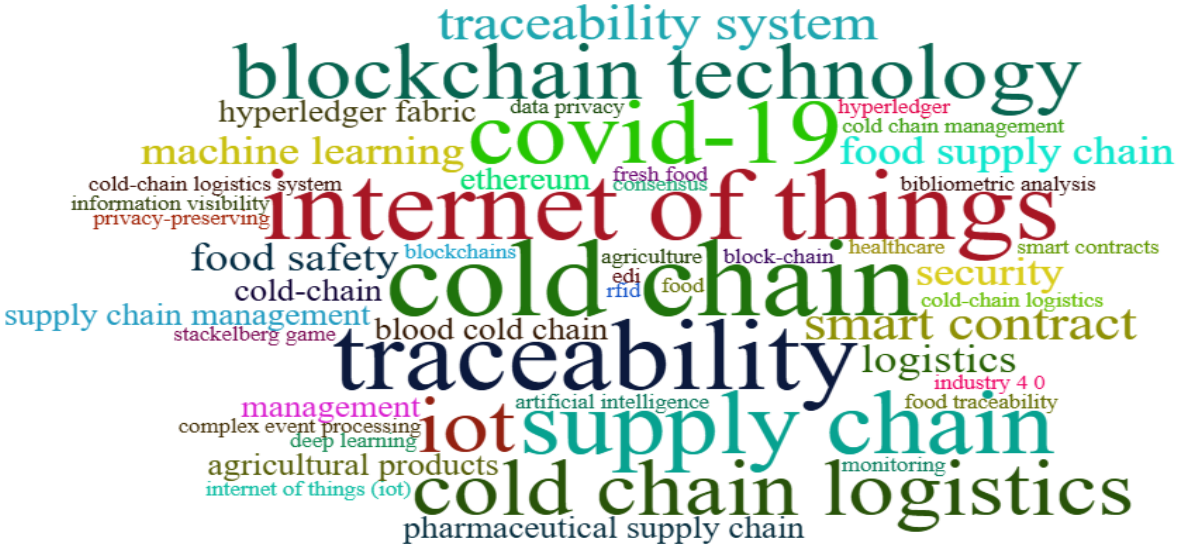
Word Cloud Mapping

Keywords can be regarded as the fundamental essence of a paper, encapsulating the core content in a concise manner (Ouyang et al., 2018; Li et al., 2019). The results of the keyword frequency analysis conducted on the authors' keywords from 112 papers are presented in Figure 6, which illustrates the mapping of the most frequently occurring keywords. The analysis was performed by word cloud mapping.

Figure 6 presents a word cloud mapping of the most frequently used keywords from the analyzed articles. The prominence of terms like "blockchain," "cold

chain," and "Internet of Things" underscores their centrality to the research field. Secondary terms, including "traceability," "smart contract," and "machine learning," highlight technological advancements and applications within cold chain logistics. The frequent appearance of "COVID-19" reflects the pandemic's influence in accelerating blockchain adoption for vaccine distribution and real-time monitoring systems. This visualization provides a concise summary of the field's core focus areas and emerging topics.

Figure 6. The Word Cloud Map of the Most-Frequently Appeared Author's Keywords



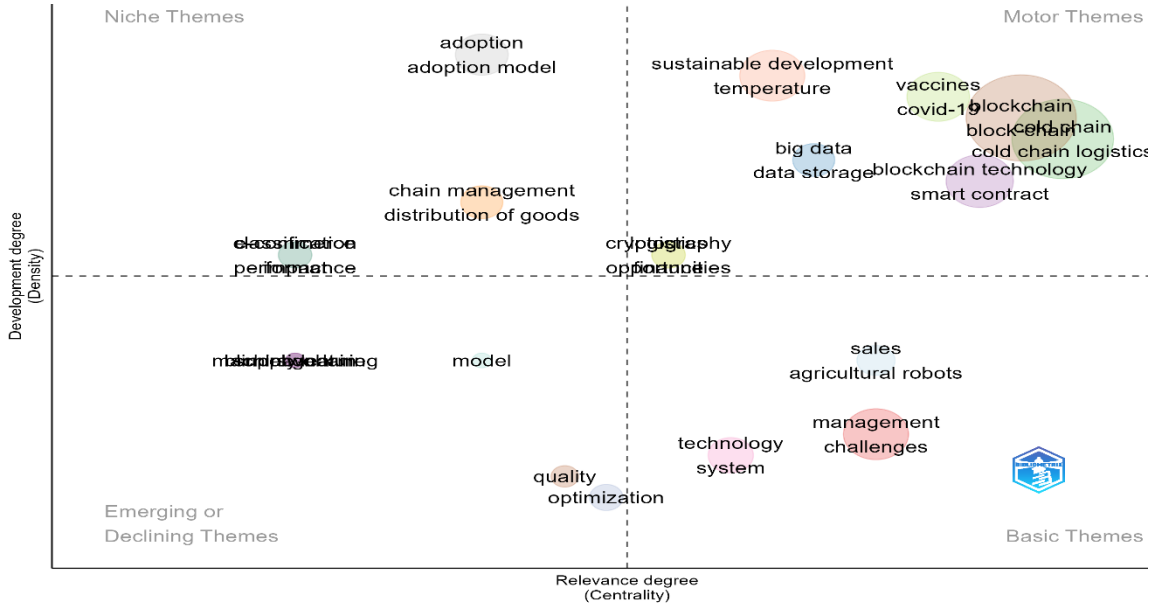
Thematic Mapping

A thematic map provides a visual representation of the principal themes within a given research area (Cobo et al., 2011; Madsen et al., 2023). This analysis employs a cluster analysis to group keywords into categories, thereby identifying the dominant themes within the field. The map is composed of two axes: centrality (x-axis) and density (y-axis). The significance of a specific theme is indicated by centrality, while the extent of its development is reflected by density. Thematic maps are typically organised into a 2x2 matrix, which results in four quadrants. The size of the bubbles used to represent the keywords is indicative of their frequency (Cahlik, 2000; Cobo et al., 2011, 2015; Alkhammash, 2023; Madsen et al., 2023).

Thematic mapping, as illustrated in **Figure** 7, provides an insightful categorization of research themes into four quadrants based on their centrality (importance) and density (degree of development). Motor themes, positioned in the upper-right quadrant, are both well-developed and highly central to the field, indicating their strong influence on the research domain. Examples of motor themes in this study include "sustainable development," "big data," and "smart contracts," which highlight the core focus areas of blockchain research in cold chain logistics. These themes are not only pivotal but also demonstrate a high degree of maturity in their research progression.

The upper-left quadrant features niche themes such as "performance" and "classification," which are well-developed yet less central. These represent specialized areas of study with potential for further integration into the broader research landscape. In contrast, the lower-right quadrant identifies emerging or declining themes like "optimization" and "quality." These themes exhibit high centrality but lower density, signaling their growing importance but indicating that they are still under development. If these areas receive greater scholarly attention, they could transition into motor themes in future studies. Finally, the lower-left quadrant contains basic themes like "management challenges" and "technology systems," which are less developed and peripheral to the main research focus.

Figure 7. The Thematic Mapping of the Most-Frequently Appeared Keywords



Thematic Evolution

Figure 8 illustrates the results of the analysis of the thematic evolution of papers on blockchain technology in cold chain logistics, based on author keywords. Thematic evolution can be analysed with regard to specific time intervals, which enables the identification of instances where topics merge or divide into several themes. Such graphs are a valuable tool for visualising the thematic evolution of a research area (Aria et al., 2022).

Figure 8. The Thematic Evaluation of Keywords

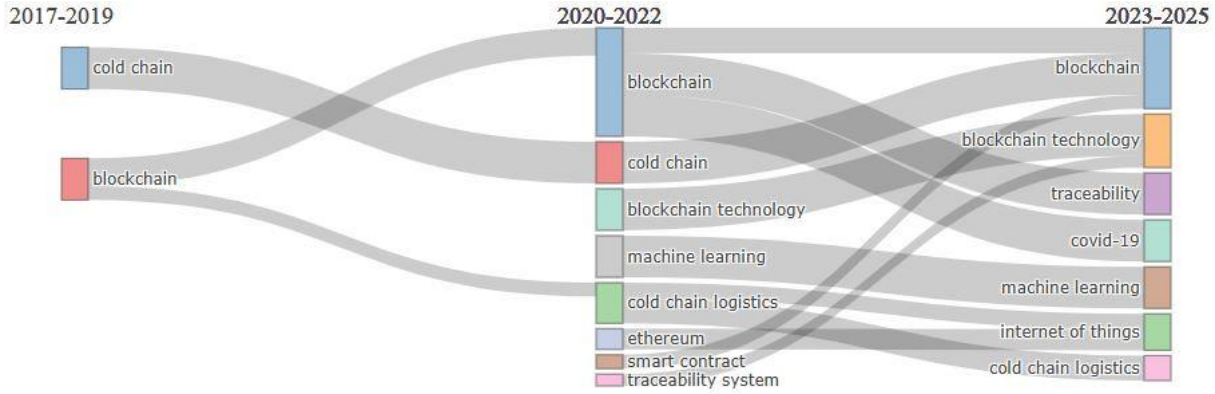


Figure 8 captures the thematic evolution across three distinct time periods: 2017–2019, 2020–2022, and 2023–2025. During the initial period (2017–2019), foundational terms like "cold chain" and "blockchain" dominated the research, reflecting the nascent stage of the field. In the second period (2020–2022), themes such as "machine learning," "smart contracts," and "Ethereum" emerged, showcasing the increasing incorporation of advanced technologies. The COVID-19 pandemic significantly influenced research during this time, as seen in the heightened focus on "traceability systems" and "vaccine logistics." In the latest period (2023–2025), terms like "IoT," "traceability," and "COVID-19" remain prominent, emphasizing the ongoing importance of transparency, real-time monitoring, and global health challenges in shaping blockchain applications in cold chain logistics.

These visualizations collectively demonstrate the dynamic nature of this research domain, highlighting established themes, identifying areas for future exploration, and showcasing how external factors like the pandemic have influenced the evolution of blockchain in cold chain logistics.

By examining these data visualizations and analyses, the study provides a comprehensive understanding of the academic landscape, identifying both established trends and emerging opportunities in blockchain research for cold chain logistics.

Co-citation Analysis

The co-citation analysis provides insights into the interconnectedness of academic studies based on shared citations, facilitating the exploration of thematic relationships within the literature (Niknejad et al., 2021). Citation analysis is a prominent methodology in bibliometrics, employing citation counts to evaluate similarities between documents, authors, or journals. Co-citation analysis is typically employed to map older research, offering a dynamic, forward-looking perspective that is most effective when applied across different time periods (Aria & Cuccurullo, 2017). The process of elucidating the structure of the literature and identifying connections between a multitude of academic studies based on references is made possible by means of co-citation analysis (Zitt & Bassecoulard, 1994; Özcan Akdağ & Tunca, 2022).

Table 6 presents the results of this analysis, which was conducted using the Bibliometrix package in R. The analysis identified a network of 20 highly cited papers, categorized into four distinct clusters. These clusters, defined by their thematic focus, represent the structural relationships and evolution of research within the analyzed field.

The chronological distribution of studies in the network highlights the historical progression of research. The earliest study in the dataset, published in 2009, is found in Cluster 1, indicating the foundational nature of this work within its thematic grouping. Conversely, the most recent publication, from 2023, is part of Cluster 4, reflecting the emergence of contemporary research themes. These temporal markers underscore the dynamic nature of scholarly inquiry, with older clusters providing a basis for subsequent developments and newer clusters introducing fresh perspectives.

The analysis revealed that Cluster 2 contains the largest number of studies, with 10 papers. This indicates a significant concentration of research activity and scholarly interest within this thematic area, potentially suggesting its central importance to the overall field. The remaining clusters have fewer papers but contribute unique thematic insights, demonstrating the diversity of research approaches and focuses represented in the network.

Table 6 also includes key centrality metrics such as Closeness, Betweenness, and PageRank, which quantify the importance of nodes (papers) within the network. Closeness centrality measures the average distance of a node to all other nodes, indicating its accessibility within the network. A node with high closeness centrality is strategically positioned to influence or be influenced by others efficiently. Betweenness centrality identifies nodes that act as bridges between different parts of the network, highlighting their role in facilitating connections between otherwise disconnected nodes (Zhang & Luo, 2017). PageRank, a pivotal metric, assesses the relative importance of nodes based on the structure of the network, reflecting their influence on the overall scholarly discourse (Zhang et al., 2022). Together, these metrics provide a comprehensive understanding of the roles and significance of individual studies within the co-citation network.

Table 6. Co-citation Analysis of Sample Papers' References

Vertex	Cluster	Betweenness Centrality	Closeness Centrality	Pagerank Centrality
behnke k 2020	1	37.1484848	0.03448276	0.05724801
abad e 2009	1	12.7418895	0.02857143	0.06427814
badia-melis r 2018	1	3.9325312	0.03030303	0.05652608
tian f 2017	2	0.2588235	0.02631579	0.06442054
feng hh 2020-1	2	0.2000000	0.02439024	0.08843080
caro miguel 2018	2	8.7901070	0.03125000	0.05443955
galvez jf 2018	2	4.5474450	0.03030303	0.07162763
kamilaris a 2019	2	2.4686275	0.02500000	0.05642492
bumblauskas d 2020	2	1.3661319	0.02631579	0.06928293
salah k 2019	2	0.7500000	0.02631579	0.05649924
george rv 2019	2	2.2939097	0.02631579	0.05668469
hobbs je 2020	2	23.5650030	0.03225806	0.03348812
kamble ss 2020-1	2	19.5836898	0.03571429	0.05460337
bamakan smh 2021-1	3	7.6322638	0.02941176	0.03669057
dutta p 2020	3	12.3686275	0.03225806	0.03916807
saberi s 2019	3	3.8446227	0.02857143	0.03105663
kumar a 2021	3	2.2203803	0.02777778	0.02412371
anand s 2022	4	0.2000000	0.02272727	0.02833567
hadipour-rokni r 2023	4	0.2000000	0.02272727	0.02833567
zhang bh 2014	4	0.2000000	0.02272727	0.02833567

Figure 9. Visualization of Co-citation Network

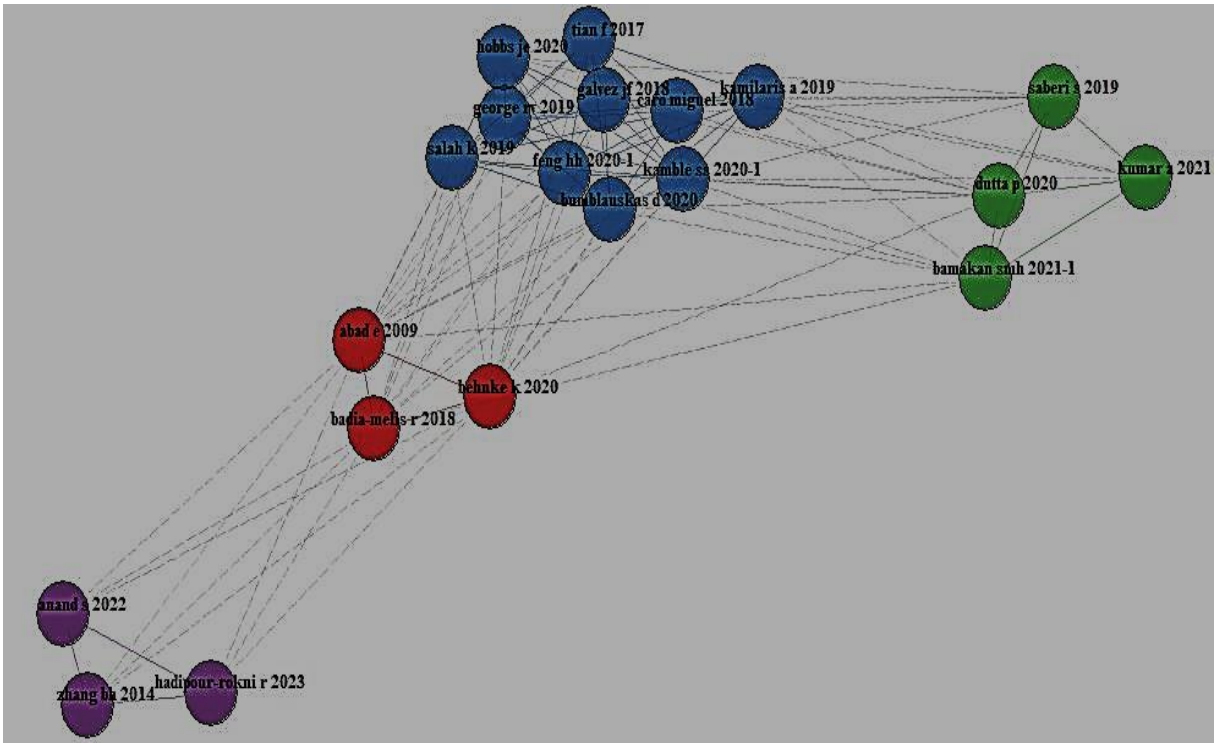


Figure 9 visualizes the co-citation network, illustrating the relationships among references based on shared citations. Each cluster is depicted using a distinct color, with red representing Cluster 1, blue Cluster 2, green Cluster 3, and purple Cluster 4. The visualization reveals the dense connections within the network, highlighting the centrality of specific papers and their pivotal roles in shaping the field. The clustering further demonstrates how research themes evolve and diverge over time, with nodes (representing individual papers) connected by lines that signify shared citations. The varying density of connections within and across clusters reflects the relative influence of papers and the thematic cohesion of the clusters.

This analysis underscores the utility of co-citation analysis as a method for mapping the intellectual structure of a research field. By examining the relationships between highly cited works, it is possible to identify influential studies, understand

the thematic evolution of research, and uncover the dynamics of scholarly discourse over time.

5. CONCLUSION

The growing complexity of global supply chains, coupled with the rising demand for transparency and reliability, has underscored the importance of innovative technologies in addressing logistical challenges. Cold chain logistics, in particular, plays a crucial role in ensuring the quality and safety of temperature-sensitive products such as vaccines, pharmaceuticals, and perishable food items. However, the susceptibility of cold chains to disruptions, inefficiencies, and fraud necessitates solutions that can enhance traceability, transparency, and operational efficiency. Blockchain technology has emerged as a promising tool to address these issues by enabling decentralized, secure, and tamper-proof data management across supply chains (Hofmann et al., 2017; Bamakan et al., 2021). Its integration with complementary technologies such as the Internet of Things (IoT) and artificial intelligence has further amplified its potential to revolutionize cold chain logistics (Cil et al., 2022; Shashi et al., 2018; Jiang et al., 2024).

This study provides a comprehensive analysis of the academic literature on blockchain applications in cold chain logistics, offering valuable insights into emerging themes, collaboration patterns, and research gaps. By employing bibliometric and co-citation methods, the research maps the intellectual structure of this rapidly evolving field. The analysis of 112 peer-reviewed papers retrieved from Scopus and Web of Science reveals key findings that enhance our understanding of blockchain's role in addressing challenges within cold chain logistics.

One of the major findings of this study is the significant surge in research interest following the COVID-19 pandemic. This increase reflects a global recognition of the need for resilient and transparent cold chain systems, particularly for the distribution of vaccines and temperature-sensitive pharmaceuticals. Blockchain's potential to ensure traceability, prevent fraud, and enhance accountability has driven its growing adoption in logistics systems worldwide (Mustafa et al., 2024; Jiang et al., 2024). The thematic analysis identifies dominant research areas, such as the integration of blockchain with IoT and machine learning, which enable real-time monitoring and predictive analytics (Badia-Melis et al., 2018; Rane et al., 2024). These advancements are particularly relevant for cold chains, where maintaining optimal temperature conditions is critical to ensuring product quality and safety.

Another important finding of this study is the identification of global collaboration patterns. The analysis highlights China and Canada as leading contributors to blockchain research in cold chain logistics, reflecting their investments in technological innovation and academic partnerships (Ramírez et al., 2022). However, the study also reveals significant regional disparities, with limited contributions from developing regions such as Africa and South America. These findings point to untapped opportunities for future research and collaboration, particularly in regions where cold chain systems are critical for food security and public health.

In terms of contributions to the literature, this study advances our understanding of blockchain's role in cold chain logistics by providing a systematic synthesis of the existing research. It identifies key trends and thematic areas, offering a structured overview of the current knowledge base. This synthesis not only highlights what is currently known but also uncovers critical gaps in the literature. For example, while significant progress has been made in understanding blockchain's technical capabilities, limited research has explored its scalability, cost-effectiveness, and implementation challenges. These issues are particularly relevant for small and medium-sized enterprises (SMEs) and developing economies, where resource constraints may hinder blockchain adoption (Si, 2022; Mustafa et al., 2024).

The practical implications of this study are equally significant. For industry practitioners, the findings underscore the potential of blockchain technology to optimize cold chain logistics by improving transparency, traceability, and operational efficiency.

Blockchain, when integrated with IoT and other advanced technologies, can enable real-time monitoring of temperature-sensitive goods, reducing the risk of spoilage and losses (Halim et al., 2021; Cil et al., 2022). This has important implications for sectors such as healthcare, pharmaceuticals, and food logistics, where product integrity is paramount. For policymakers, the study highlights the need for standardized blockchain protocols and regulatory frameworks to facilitate global adoption and interoperability (Shen et al., 2022; Zhang et al., 2022).

While this study makes important contributions, it also has certain limitations that should be acknowledged. First, the analysis is limited to peer-reviewed papers retrieved from Scopus and Web of Science, which may exclude relevant gray literature and industry reports. Second, the focus on English-language publications may result in a bias towards research conducted in English-speaking countries. Future studies could address these limitations by incorporating a broader range of sources and languages to provide a more comprehensive analysis.

Building on the findings of this study, several opportunities for future research emerge. First, future studies should explore the scalability and cost-effectiveness of blockchain technologies in cold chain logistics, particularly in resource-constrained settings. Research focusing on implementation challenges, such as interoperability, cybersecurity, and regulatory barriers, would provide valuable insights for both academics and practitioners. Second, interdisciplinary research that combines blockchain with other emerging technologies, such as artificial intelligence, big data analytics, and robotics, holds significant potential to drive innovation in cold chain systems (Hofmann et al., 2017). Third, there is a need for region-specific studies to address the unique challenges faced by developing economies, where cold chain infrastructure is often underdeveloped.

In conclusion, this study provides a structured and comprehensive analysis of blockchain research in cold chain logistics, contributing to both theory and practice. By uncovering thematic trends, collaboration networks, and research gaps, the study offers valuable insights for academics, practitioners, and policymakers. The findings highlight blockchain's potential to address critical challenges in cold chain logistics, particularly in ensuring transparency, traceability, and efficiency. As global supply chains continue to evolve, blockchain technology will play an increasingly important role in building resilient and sustainable logistics systems. Future research that addresses scalability, implementation challenges, and cross-regional collaboration will be essential to fully unlock the transformative potential of blockchain in cold chain logistics.

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