

Improving green supply chain resilience through Blockchain innovation: A risk mitigation perspective

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Abstract. The increasing popularity of cryptocurrencies has brought to light the underlying technology known as Blockchain. This innovation is a decentralized information management system that allows for the recording of digital asset transactions without the need for institutional intermediaries. The potential of Blockchain to revolutionize the management of companies, particularly in the context of supply chain risk management, is immense due to the complex and vulnerable nature of the supply chain. This article aims to highlight the impact of the Blockchain on the risks observed in the Supply Chain by examining how this innovation can strengthen the resilience of these chains in times of increased threat and uncertainty. Our study, which utilizes a bibliometric analysis, highlights the role of Blockchain technology in mitigating various risks, including those related to fraud, errors, loss of information, and supply chain failure. It should be noted that the implementation of environmental supply chain practices requires the commitment and participation of all stakeholders involved in the supply chain, as well as favorable policies and incentives from governments and institutions to encourage the adoption of sustainable practices. The key features of Blockchain, including real-time transparency, traceability, and automated smart contract management, enable risk mitigation and contribute to the overall resilience of green supply chains.

Keywords: Blockchain technology, green supply chain, resilience, risk, supply chain management.

1 Introduction

Our discourse begins by acknowledging the ubiquity of chaos in today's world, particularly within the financial system, highlighting the validity of Murphy's Law or the Law of Finals, which predicts pessimistic outcomes. Financial scandals are increasingly prevalent, and media coverage tends to focus on complex risks associated with corporate wrongdoing, as well as political, economic, and health instability exacerbated by the COVID-19 pandemic and climate change. The ongoing war in Ukraine and its significant impact on the economy further compounds these issues [1, 2]. Organizations are facing a growing sense of weakness as multiple crises continue to arise. Indeed, the current crisis has brought to light the vulnerabilities especially in the supply chain, from the procurement of materials to the final delivery of products to the customer's doorstep [3]. Each link in the chain is under significant pressure, leaving the entire system at risk. Blockchain has emerged as a potential solution for

the vulnerabilities in supply chain management. It offers a decentralized, transparent system for tracking and verifying transactions without the need for a centralized authority. This distributed ledger operates through a network of computers, where each computer maintains a copy of the ledger, ensuring that any changes made are recorded and verified by multiple participants [4]. While risk, and blockchain are topics of increasing significance, the current literature on supply chain management lacks a systematic synthesis of these concepts and their interrelationships. This study endeavors to address this gap in the literature through the use of novel bibliometric analyses. Our paper focuses on the impact of blockchain on risk reduction in the supply chain, and aims to answer several research questions. These include identifying the most influential authors, countries, and publications in the field, as well as analyzing the evolution of co-citation analysis. The study also examines the newest and emerging patterns in this area of research, and explores the risks associated with the supply chain and how blockchain technology can be used to create a more resilient green supply chain. By providing transparency, traceability, and automated smart contracts, blockchain mitigates risks such as fraud, non-compliance, and supply chain failures. This risk reduction contributes to the development of a green resilient blockchain by ensuring that sustainability practices are followed, environmental standards are met, and ethical sourcing is upheld throughout the supply chain. With improved visibility and accountability, blockchain helps prevent unethical practices and ensures that environmentally friendly actions are accurately recorded and verified. By promoting trust, integrity, and efficiency, blockchain technology enables the establishment of a resilient supply chain that prioritizes sustainability and minimizes environmental impacts, thus paving the way for a greener and more sustainable future [5]. We used a comprehensive bibliometric analysis using VOSviewer to investigate the literature and address the research questions at hand. Over 1 114 academic publications were analyzed using this method to visualize the knowledge structure and provide a rapid overview of the current state of the field. Performing a bibliometric research on improving green supply chain resilience through blockchain innovation from a risk mitigation perspective is important as it provides a systematic overview of the existing literature, identifies research gaps, evaluates the impact of previous studies, and offers practical implications for industry professionals and policymakers. This research contributes to the advancement of the field by guiding future research efforts, highlighting key contributors and influential works, and translating research findings into actionable insights for building sustainable and resilient supply chains.

The article is organized as follows: the methodology section briefly explains the history and methodology of bibliometric analysis used in this study. The results and discussion section presents the distribution of retrieved papers over time and employs various analytical methods to identify influential articles, authors and countries in the field. Then, we examine the risks associated with the supply chain based on bibliometric analysis and explore how blockchain can be utilized to reduce these risk. The article concludes by discussing its limitations.

2 Methodology

The aim of this research was to conduct a comprehensive analysis of the existing literature to examine the impact of blockchain technology in reducing risks within the supply chain and its potential contribution to building a more environmentally friendly and resilient supply chain. To achieve this goal, a bibliometric analysis methodology was utilized, which has

gained popularity among scholars due to its ability to process large quantities of data and adapt to various software applications and information sources [6]. At the start of the study, we conducted a thorough literature search using the Scopus database, which is highly regarded among scholars. We used relevant keywords and did not limit the types of documents analyzed, resulting in an unbiased review of the literature. After applying our inclusion criteria, which were limited to open access documents in either French or English language, we reduced our initial set of 1 114 documents to 213. **Search string:** TITLE-ABS-KEY (“blockchain” OR “block chain” OR “distributed ledger”) AND TITLE-ABS-KEY (“security” OR “risk” OR “threat” OR “disruption” OR “resilience” OR “crime” OR “attack” OR “breach” OR “failure”) AND TITLE-ABS-KEY (“supply chain”). We collected and prepared data for analysis by extracting key information such as authors, titles, publication years, and affiliations. In the third stage, we used VOSviewer software to conduct a bibliometric analysis of 213 articles. By tracking research trends and geographical distribution, we gained insight into the evolution of the field over time. Furthermore, we utilized the same software to conduct a keyword analysis, which allowed us to identify the most commonly used terms in the literature. We then employed cluster analysis to group these keywords based on their co-occurrence patterns and presented the results in a visual representation using a clusters heatmap. Thanks to the bibliometric analysis conducted, we were able to identify relevant literature discussing the potential of blockchain to reduce risks in the supply chain. This analysis helped us to develop a conceptual framework that outlines the potential applications of blockchain in mitigating risks in the supply chain.

3 Results

In this results section, our objective is to provide a comprehensive analysis of the current state of the impact of blockchain technology in establishing a resilient supply chain. We will begin by examining the overall scientific output in this field, encompassing subject area analysis and a detailed breakdown of contributions by country. Additionally, we will investigate the most significant and influential studies within this domain. Moreover, a citation analysis will be conducted to identify the key studies and authors that have had a substantial influence in this field. Lastly, we will employ keyword and cluster analysis to uncover emerging research trends and highlight potential areas for further exploration.

3.1 Current status of the field

Based on the graph presented, it is evident that the field of study under consideration started gaining momentum in 2017. Since then, the number of documents published on this topic has been steadily increasing. This implies that the field is still in its early stages, and there is a vast scope for further exploration and development. The increasing research interest in the impact of blockchain on reducing risks in the supply chain can be attributed to the advantages it offers in terms of secure and transparent transaction tracking and verification. Furthermore, the emergence of the concept of a green resilient supply chain has also contributed to the increased attention given to blockchain technology. As organizations strive to adopt environmentally friendly practices and comply with sustainability standards, blockchain's features of transparency, traceability, and automated smart contracts hold the potential to enhance the resilience of supply chains while promoting green initiatives. Therefore, the rising interest in exploring the intersection of blockchain and supply chain risk reduction is not only driven by its technological advantages but also by the growing need to establish sustainable and resilient supply chains that minimize environmental impact.

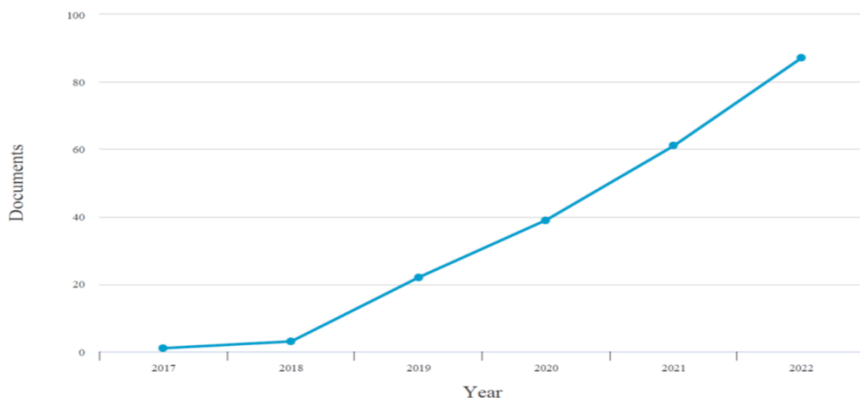


Fig.1. The distribution over time of articles retrieved from the Scopus database.

3.2 Documents by subject area Figure 2 shows that this topic covers a broad range of subject areas, as expected. This diverse distribution emphasizes the significance of Blockchain and its relevance in various academic fields. The analysis revealed that the majority of publications (15.7%) were categorized under the field of social sciences, followed by Computer Science (15.1%), and Business, Management, and Accounting (14%). The subject of engineering, decision science and environmental sciences also contributed significantly to the distribution (total of 34.3%).

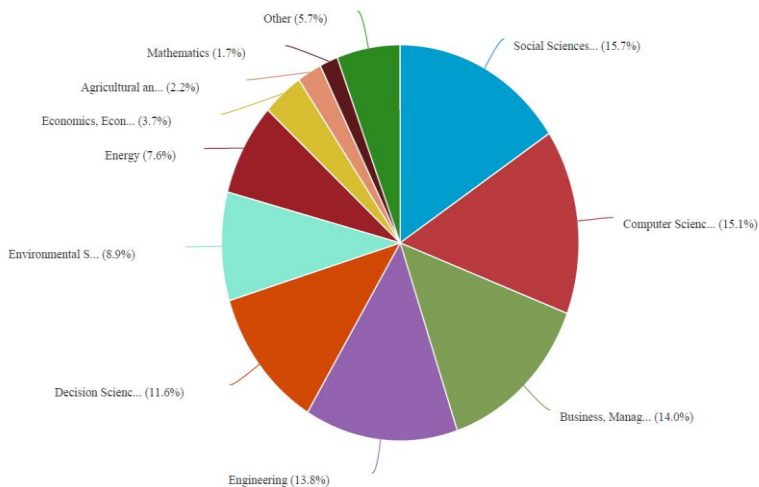


Fig.2. Document by subject area (obtained thanks to Scopus)

3.3 Scientific Production by Country

The study's findings, presented in Figure 3, suggest that research into the use of blockchain to reduce risks in the supply chain has primarily been conducted in China. China emerged as the leading contributor, with almost 50 published documents, followed by the United States

and India. This may be attributed to various factors, including these countries' significant roles in global supply chain management and their recent emphasis on technology and innovation. These results highlight the increasing importance and interest in blockchain technology in different parts of the world, and demonstrate its potential for enhancing supply chain management and mitigating risks. Indeed, the global interest in blockchain technology for supply chain management signifies a broader recognition of the need for enhanced visibility, security, and sustainability in global trade. Governments, industry leaders, and research institutions across the world are actively exploring and investing in blockchain solutions to transform supply chains and create more resilient and efficient systems.

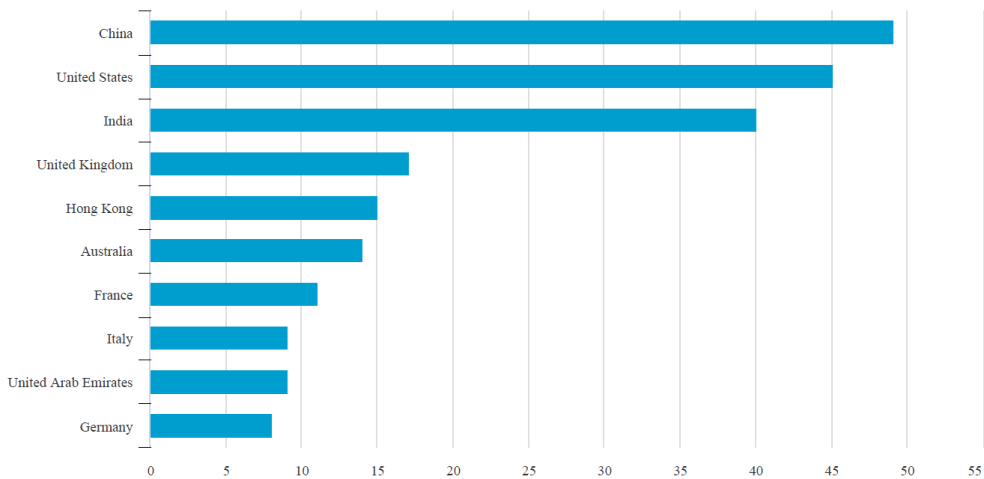


Fig.3. Top 10 most prolific countries.

3.4 Most relevant contributions

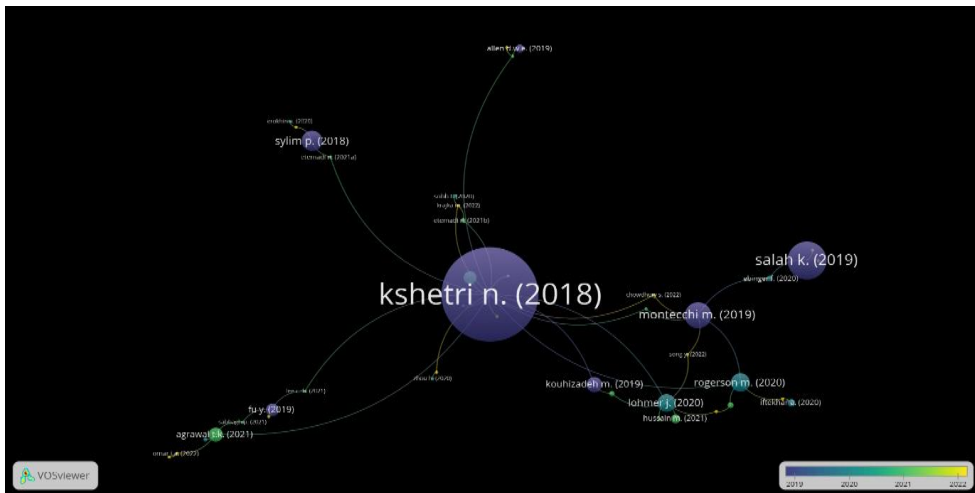


Figure 4. Co-citation author’s network (created by VOSviewer).

Figure 4 provides an overview of the most prolific authors who have made significant contributions to the research on blockchain in the supply chain. Their collaborative efforts have advanced knowledge and understanding of these phenomena, resulting in significant progress in these fields. Notably, the figure highlights author Kshetri (2018) who has been cited 765 times for his article "Blockchain’s roles in meeting key supply chain management objectives". The paper explores the potential impact of blockchain on crucial objectives within supply chain management, including cost, quality, speed, dependability, risk reduction, sustainability, and flexibility. It delves into how blockchain technology is expected to influence and shape these aspects of supply chain operations [7].

3.5 Blockchain for risk reduction in Supply Chain: Analyzing research trends

Keyword occurrence and co-occurrence analysis are widely used techniques in bibliometrics to identify critical trends in a particular research field [6]. In this study, we employed these techniques to evaluate the importance of blockchain in reducing risks in the supply chain. Specifically, we analyzed 2000 keywords and generated a co-occurrence map from 53 keywords that appeared four or more times in all collected documents. As shown in Figure 5, the term "Blockchain" was the most frequently used keyword, with a total of 237 instances identified. The term "Supply Chain Management" was observed 166 times and was found to be closely associated with the term "risk", which appeared 90 times. These three keywords had 44 links in common, indicating the number of publications in which they appeared together.

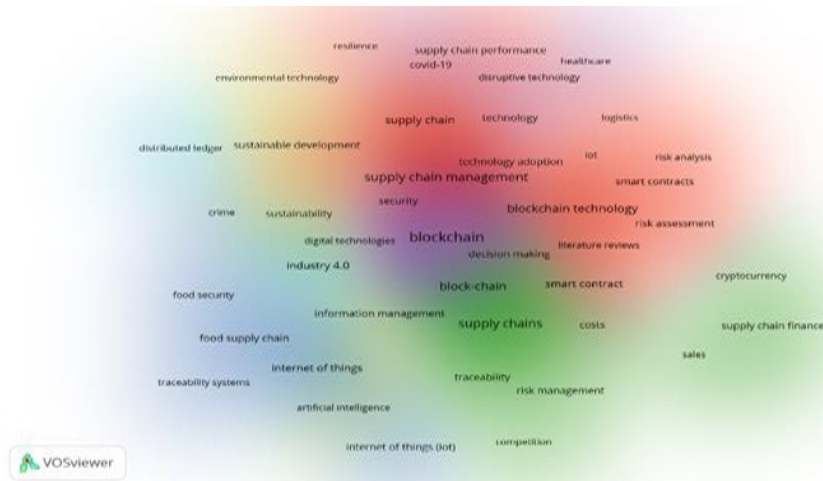


Figure 5. Cluster density visualization

In the subsequent stage of our study, we employed the cluster visualization technique to enhance our understanding of the intellectual landscape of blockchain and risks in the supply chain. This method identifies sets of keywords exhibiting co-occurrence relationships and labels them according to their primary research theme. As customary in VOSviewer, numerical labels and colors were assigned to clusters, as illustrated in the table below. Our analysis enhances understanding of the complex and evolving nature of blockchain and supply chain risks by examining the interrelationships among key keywords in the field.

Table 1. Cluster Characteristics in Co-Citation Analysis: A Summary Table

Cluster	Colour	Items	Main items	Label
Cluster 1	Red	16	Blockchain; risk management; smart contracts; supply chain management,	Smart contracts in supply chain management
Cluster 2	Green	11	Blockchain, Cryptocurrency, Supply chain finance, Risk management, Cost , Sales	Blockchain and supply chain finance.
Cluster 3	Blue	10	Internet of things; crime, food safety; food security; food supply chain; traceability	Blockchain and the food supply chain
Cluster 4	Yellow	09	Sustainability, Environmental technology, Artificial intelligence, Sustainable	Blockchain and the sustainability of supply chains
Cluster 5	Purple	08	Blockchain, Technology, Healthcare, Covid19, Security	The Blockchain and the health system.

In our analysis, we identified five distinct clusters of co-occurring keywords, each representing a specific theme within the impact of blockchain on creating a resilient supply chain. Let's elaborate on each cluster: The first cluster focuses on the utilization of smart contracts in supply chain management. Smart contracts are self-executing contracts with the terms of the agreement directly written into code. Within this theme, researchers explore how smart contracts can streamline and automate various

supply chain processes, such as procurement, inventory management, and contract fulfillment [8, 9]. The second cluster delves into the intersection of blockchain technology and supply chain finance. Researchers investigate how blockchain can revolutionize traditional financial processes within supply chains, including payment settlements, invoice financing, and trade finance. By leveraging blockchain's inherent transparency and immutability, stakeholders aim to enhance financial efficiency, reduce fraud, and improve trust in supply chain finance operations [10,11].The third cluster examines the application of blockchain technology in the food supply chain. It explores how blockchain can improve traceability, transparency, and quality assurance in the food industry. By implementing blockchain solutions, stakeholders can track and verify the origin, production, and distribution of food products, enhancing food safety, reducing fraud, and promoting consumer trust [12].Blockchain and the Sustainability of Supply Chains: This cluster emphasizes the sustainability aspect of supply chains by incorporating blockchain technology. Researchers explore how blockchain can contribute to building sustainable supply chains by enabling transparent tracking of environmental impact, ethical sourcing, and responsible production practices. The integration of blockchain in creating a green resilient supply chain helps promote eco-friendly practices, reduce waste, and support sustainable development goals.Indeed, Blockchain provides a decentralized and immutable ledger that enables the recording and verification of environmental data at various stages of the supply chain. This includes tracking carbon emissions, energy consumption, waste generation, and other relevant environmental metrics. Another area of interest is ethical sourcing and responsible production practices. Blockchain can facilitate the traceability and verification of raw materials and components used in the supply chain. Through the use of unique identifiers and smart contracts, stakeholders can track the origin and journey of products, ensuring that they are sourced from sustainable and socially responsible suppliers. This can help prevent the use of conflict minerals, promote fair labor practices, and support responsible sourcing initiatives. Furthermore, the integration of blockchain in creating a green resilient supply chain can help promote eco-friendly practices and reduce waste. By establishing a transparent and decentralized system, blockchain enables the efficient sharing and utilization of resources. It can facilitate the implementation of circular economy principles, such as product reuse, recycling, and remanufacturing, by providing a trusted platform for recording and verifying transactions [3, 5, 13].

The last cluster focuses on the application of blockchain technology in the healthcare sector and the overall health system. Researchers explore how blockchain can improve data interoperability, patient privacy, and secure medical records. By leveraging blockchain's decentralized and immutable nature, stakeholders aim to enhance data security, streamline healthcare processes, and enable seamless information exchange across healthcare providers [14].

3.6 Mitigating Risks and Building a Green Resilient Supply Chain with Blockchain Technology

After dissecting the literature, we were able to compile the following table (Table 2) that groups together the important risks a supply chain may experience. The supply chain is a crucial component of any business, and it is vital to understand the various risks that can impact its functionality. The risk factors can be classified into four primary categories: planification, supply, production, and return processes. Understanding the nature of the risks

and implementing strategies to mitigate them is essential for ensuring the smooth functioning of the supply chain [7, 3, 15, 16, 10, 17].

Table 2 . List of Risks Seen in the Supply Chain

Plan:	Source:	Make:	Deliver:	Return:
Changes in customer demand Delay in delivery from suppliers Demand Forecast Errors Inability to manage supply chain complexity Loss of production capacity	Supplier security risks Financial instability of suppliers Shortage of raw materials Supply chain disruptions due to natural disasters or political events Risks of fraud or corruption	Equipment breakdowns Production interruptions due to maintenance errors Non-compliance with quality or safety standards Delays in launching new products	Delivery delays or non-delivery Logistic disruptions, such as traffic jams or vehicle breakdowns Order processing errors Shipping costs higher than expected Theft or damage to products in transit	Defective or damaged products Order or delivery errors High return and repair costs Returned product tracking and tracing issues Fraud related to product returns

We'll explore how blockchain can mitigate the risks mentioned in supply chain management by highlighting its unique features that facilitate risk reduction:

Decentralization of information: by utilizing a decentralized network of nodes, each participant in the supply chain can access the same information, leading to greater accountability. This, helps to reduce the risk of fraudulent activities, such as double-spending or tampering with data, as each transaction is recorded on the blockchain and is visible to all participants. Furthermore, decentralizing information ensures that there is no central point of failure, which reduces the risk of cyber-attacks or disruption in the pandemic situation. This innovative application of blockchain technology contributes to the establishment of a green resilient supply chain that promotes environmentally-friendly practices and supports sustainable development goals [3, 18].

Asset tracking: The use of blockchain allows for the tracking of goods and services from the point of origin to the end-user, enabling a transparent record of the supply chain. This reduces the risk of counterfeiting, as each item can be traced back to its source. Additionally, blockchain-based asset tracking facilitates efficient inventory management, ensuring optimal resource utilization and minimizing waste, further contributing to the overall resilience and sustainability of the supply chain [19].

Data transparency and immutability by advanced cryptographic algorithms: By using blockchain, data can be stored in an immutable manner, ensuring that it cannot be altered or tampered with. Blockchain can expedite order fulfillment processes by providing paperless and easily accessible customer records. It quickly confirms customer credit history, inventory status, and finances, while also notifying order/shipment status and providing transparency throughout the process. The transparency of data enables greater visibility in the supply chain, reducing the risk of unethical practices. It helps in verifying and validating eco-friendly practices, ethical sourcing, and responsible production methods, creating

accountability throughout the supply chain. Advanced cryptographic algorithms secure data on the blockchain, reducing the risk of cyber-attacks and data breaches [8].

Automation of Processes: Smart contracts are a key component of blockchain, enabling the simplification of supply chain processes. They are self-verifying and self-executing agreements that reduce the risk of errors and fraudulent activities. By eliminating intermediaries, they enable automatic execution of transactions on the blockchain, reducing delays and improving compliance. This streamlines supply chain management, making it easier to manage and reducing the risk of misunderstandings [20, 10]. Automation reduces paperwork, eliminates redundant processes, and enables real-time monitoring, allowing prompt identification and resolution of environmental issues. This efficient and automated approach promotes transparency, traceability, and accountability, leading to a more ethical and environmentally responsible supply chain [5].

4 Conclusion

Blockchain has the potential to revolutionize supply chain management by reducing risks such as fraud, and data breaches, and creating a resilient green supply chain. This study analyzes 213 publications from Scopus to provide an in-depth analysis of the current state of research in this area. VOSviewer was used to perform network and visualization analyses, resulting in the identification of key journals and emerging themes and concepts within the field. The study presents a comprehensive analysis of publication trends over time, identifying key gaps in the literature, and highlighting the main risks observed in the supply chain. The analysis also shows that international collaboration has contributed to the pace of scientific publications, with the United States and China being the most productive countries. The use of blockchain in supply chain management is discussed, with its decentralization, tracking, and smart contracts being identified as characteristics that reduce risks. During our bibliometric analysis, we discovered a notable trend in research that emphasizes the importance of improving green supply chain resilience through the adoption of new technologies such as blockchain. The study's findings provide significant insights into the potential of blockchain technology in enhancing the resilience of green supply chains. Moreover, the research demonstrates that blockchain not only addresses supply chain risks but also establishes a solid foundation for building sustainable and resilient supply chains. This aligns with the increasing market demands for environmentally responsible practices and ethical supply chain management. Companies that prioritize green supply chain resilience through blockchain innovation can gain a competitive advantage by satisfying these market demands, attracting environmentally conscious consumers, and positioning themselves as frontrunners in sustainability.

Although the current study provides valuable insights, it is important to acknowledge its limitations. One limitation is the use of only the Scopus database, which may have excluded relevant articles from other sources. Additionally, while bibliometric analysis provides valuable insights, it cannot fully explain the underlying factors behind the results. To gain a deeper understanding of the research gaps, future research could incorporate social science methods such as expert interviews, case studies, or surveys.

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