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Integrating Blockchain Technology in Supply Chain Management: A Bibliometric Analysis of Theme Extraction via Text Mining

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Abstract: The integration of blockchain technology into supply chain management (SCM) has emerged as a revolutionary force transforming traditional business operations. This study uses bibliometric analysis on 1069 articles from the Scopus database, using text mining and Python to uncover predominant themes and research trends at the intersection of blockchain and SCM. The key findings revealed three main thematic groups: 'blockchain to improve transparency and traceability in SCM' (supported by 323 articles), 'impact of blockchain on supply chain efficiency and cost reduction' (295 articles), and 'blockchain-enabled supply chain resilience' (191 articles). Furthermore, text mining highlighted prominent themes such as 'decentralized supply chain networks' (204 articles), 'smart contracts for automated processes in SCM' (234 articles), and 'blockchain for sustainable supply chain practices' (227 articles). The inclusion of sustainability themes reflects the growing importance of environmentally conscious strategies within supply chains, driven by the capacity of blockchain to reduce waste, and promote resource efficiency. The study identifies critical literature gaps, advocating for further exploration of the socio-economic impacts of blockchain on SCM. The topic extraction suggests new directions for SCM theory, while the role of blockchain in fostering sustainable and ethical supply chains is underscored. Practically, blockchain and IoT emerge as pivotal in the advancement of SCM, with text mining offering industry foresight and emphasizing blockchain-driven resilient strategies. Limitations include reliance on a single database and the recommendation that future studies incorporate diverse sources and qualitative insights. The findings provide a roadmap for academics and practitioners, highlighting potential avenues in SCM, especially in the context of sustainable and ethical practices.

Keywords: blockchain technology; sustainable supply chains; supply chain resilience; transparency; traceability

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1. Introduction

Blockchain technology, especially in supply chain management (SCM), offers revolutionary innovations with great potential to transform business operations. Traditional SCM methods face various challenges, such as lack of transparency, inefficiencies, and vulnerability to disruptions, while blockchain technology can provide solutions to these issues. Blockchain, as a decentralized and immutable ledger system, ensures that all transactions are recorded and accessible by authorized stakeholders. This increases the traceability of products, reduces fraud, and ensures compliance with regulatory standards [1,2]. The adoption of blockchain technology in supply chains has the potential to improve operational efficiency and reduce costs. By automating transactions through smart contracts, which eliminate intermediaries and speed up processes, the blockchain reduces human error and fraud, while also alleviating administrative burdens [3,4]. For example, in logistics, smart contracts can automate payments upon delivery and verification of goods, thereby reducing costs and increasing operational efficiency. In addition, blockchain technology plays a critical role in supporting sustainable practices by reducing the environmental impacts of supply chains [5]. This technology can also improve trust and collaboration among supply chain partners, contributing to more resilient and sustainable global supply chains.

Blockchain technology is poised to revolutionize supply chain management (SCM) and logistics by addressing the long-standing issues of transparency, efficiency, and traceability. Traditional SCM methods often struggle with complexities, such as lack of transparency, inefficiencies, and vulnerability to disruptions. Blockchain offers a decentralized and immutable ledger system that records all transactions and makes them accessible to authorized stakeholders, improving product traceability and reducing fraud [6,7]. By ensuring data integrity and compliance with regulatory standards, blockchain technology significantly improves the reliability and efficiency of supply chains [8].

The adoption of blockchain in supply chain operations also presents substantial opportunities to improve operational efficiency and reduce costs. Smart contracts, which automate transactions and eliminate the need for intermediaries, streamline processes, and reduce human error and fraud [9]. This automation is particularly beneficial in logistics, where it can facilitate faster and more accurate payment processing after delivery verification, thereby improving operational efficiency and reducing administrative burdens. In addition, blockchain supports sustainable practices by ensuring transparency and accountability in supply chains, thus reducing environmental impacts [10]. The integration of blockchain technology into SCM not only fosters trust and collaboration among supply chain partners but also contributes to the development of more resilient and sustainable global supply chains.

Blockchain technology, renowned for its role in revolutionizing the financial sector, is making significant strides in transforming supply chain management (SCM). This integration promises improved transparency, improved efficiency, and increased resilience across supply chains. The research question driving this study is: "how does the integration of blockchain technology impact the transparency, efficiency, and sustainability of supply chain management?"

To address this question, several hypotheses are proposed:

H1: *Blockchain technology significantly improves transparency and traceability within supply chains.*

H2: *The integration of blockchain leads to improved operational efficiency and cost reduction in SCM.*

H3: *Blockchain technology contributes to the resilience and sustainability of supply chains.*

These hypotheses are directly related to the title of the paper, as they focus on the impact of blockchain on key operational and strategic areas of SCM: transparency, efficiency, and sustainability. The bibliometric and text mining approach allows us to test these hypotheses by analyzing patterns and trends in the literature, thus extracting themes that reflect the state of research in these areas. In summary, the title of the paper encapsulates the methodology and scope, while the research question and hypotheses operationalize the focus of the study on the integration of blockchain in SCM. Together, they form a coherent framework that ensures the alignment of research objectives, methodology, and findings.

Blockchain is significant in SCM. The modern supply chain is a complex and multifaceted network that requires meticulous coordination and management. Traditional SCM methods often struggle with issues such as lack of transparency, inefficiencies, and vulnerability to disruptions. Blockchain technology, with its decentralized and immutable ledger system, presents a groundbreaking solution to these challenges. One of the foremost advantages of blockchain technology in SCM is its ability to provide unparalleled transparency and traceability. Each transaction or movement of goods is recorded on the blockchain, creating an immutable audit trail that can be accessed by all authorized stakeholders. This transparency ensures that all parties can verify the authenticity and origin of products, reducing fraud and ensuring compliance with regulatory standards. For example, in the food industry, blockchain can trace the journey of produce from farm to table, ensuring safety and quality control. Improving operational efficiency and cost reduction, blockchain technology also has the potential to streamline operations and reduce costs significantly. By automating transactions through smart contracts, which are self-executing contracts with the terms of the agreement directly written into code, the blockchain eliminates the need for intermediaries. This automation not only speeds up processes, but also reduces the risk of human error and fraud. For example, in logistics, smart contracts can automate the payment process once goods are delivered and verified, thus reducing administrative overhead and improving efficiency. Blockchain also fosters supply chain resilience and sustainability. The resilience of supply chains, especially in the face of global disruptions, such as pandemics or natural disasters, is another critical area where blockchain technology can make a substantial impact. By providing real-time data and facilitating better collaboration among supply chain partners, blockchain improves the ability to manage risks and respond effectively to disruptions. In addition, blockchain supports sustainable practices by enabling companies to monitor and report their environmental and social impact, thus promoting ethical procurement and reducing the carbon footprint.

The choice of bibliometric analysis is justified by its ability to systematically review and synthesize a large volume of academic publications. Unlike traditional literature reviews or case studies that may focus on a limited number of articles or specific case examples, bibliographic analysis allows one to examine research trends, themes, and gaps in a broader scope of studies. Using bibliometric techniques, we can identify key thematic clusters, the most influential studies, and evolving research directions in blockchain and SCM. This is particularly important in rapidly evolving fields like blockchain, where understanding the trajectory of research can help both academics and practitioners make informed decisions.

Furthermore, bibliometric analysis provides quantitative insights into how frequently certain themes or concepts appear in the literature, offering a more objective and data-driven approach to summarizing the state of research. This method enables us to extract patterns that may not be apparent through more qualitative methods. Given the scope and complexity of the blockchain-SCM literature, bibliometric analysis is the most appropriate method to ensure a thorough and structured exploration of the field, highlighting both well-established and emerging themes that have the potential to shape future research.

This study employs a bibliometric analysis of 1069 articles from the Scopus database, utilizing text mining and Python to uncover predominant themes and research trends in the intersection of blockchain and SCM. Data collection targeted articles published up to 30 June 2023, focusing on themes such as "blockchain for enhancing transparency and traceability", "impact of blockchain on supply chain efficiency and cost reduction", and "blockchain-enabled supply chain resilience". In this study, the integration of blockchain technology into supply chain management (SCM) not only improves operational efficiency but also has significant potential for sustainability. The transparency and traceability offered by blockchain provide clear insights into the environmental and social impacts of supply chain processes, helping companies achieve their sustainability goals. In particular, in areas such as reducing carbon footprints, monitoring ethical sources, and reporting on sustainable practices, the blockchain demonstrates its critical importance in advancing sustainability efforts. Additionally, the decentralized nature of blockchain facilitates more efficient use of resources, helping prevent waste and unnecessary consumption. In this context, sustainability is no longer just a theoretical concept, but has become a practical and measurable objective within supply chains, thanks to blockchain technology. Although the existing literature provides valuable information on the integration of blockchain technology in supply chain management (SCM), significant gaps remain that this study aims to address. One key gap is the limited exploration of the socio-economic impacts of blockchain in SCM, particularly concerning small and medium-sized enterprises (SMEs). Although much of the current research focuses on the potential for cost reduction and transparency, less attention has been paid to how blockchain adoption affects SMEs in terms of resource allocation, barriers to technology adoption, and long-term sustainability. Additionally, while blockchain's role in enhancing transparency and traceability is well documented, there is a lack of comprehensive studies examining its scalability, especially in global supply chains with high transaction volumes and complex networks. This study seeks to fill these gaps by conducting a bibliometric analysis that not only maps existing research trends, but also identifies underexplored areas, such as the regulatory challenges and legal frameworks needed for wider blockchain adoption. By addressing these overlooked dimensions, our study aims to contribute to a more holistic understanding of the role of blockchain in transforming supply chain management practices.

2. Review of the Literature

2.1. Blockchain and Transparency

Blockchain technology has emerged as a transformative force in supply chain management (SCM), primarily due to its ability to improve transparency and traceability. Transparency in supply chains is crucial to maintaining trust among stakeholders, ensuring compliance with regulatory standards, and preventing fraud. Traditional SCM methods often face challenges with these aspects due to complexity and lack of visibility throughout the supply chain network. Blockchain, with its decentralized and immutable ledger, offers a robust solution to these challenges. Francisco and Swanson [1] emphasize that blockchain technology can significantly improve transparency in supply chains by providing a tamper-evident and auditable record of all transactions. This transparency ensures that all parties, from manufacturers to end consumers, can verify the authenticity and origins of the products. For example, in the food industry, blockchain can track the journey of products from farm to table, ensuring safety and quality control. The ability to track products through each stage of the supply chain not only enhances transparency, but also reduces the risk of fraud and counterfeiting.

Feng et al. [7] further emphasize the benefits of blockchain in improving agri-food traceability. Their study reviews the development methods, benefits, and challenges associated with the application of blockchain technology in agri-food supply chains. They found that blockchain can ensure data integrity and provide a reliable mechanism to track the provenance of food products. This is particularly important in scenarios where food safety is paramount, such as tracking the source of contamination during a foodborne illness outbreak. Kouhizadeh and Sarkis [5] explore the potential and perspectives of blockchain in greening supply chains. They argue that blockchain can support sustainable practices by ensuring transparency in the sourcing and production processes. For example, companies can use blockchain to verify that their products meet environmental and social standards, thus promoting ethical procurement and reducing the carbon footprint. This transparency is critical for companies that want to meet consumer demand for sustainable products and adhere to stricter regulatory requirements. For secure transactions, the combination of AI and blockchain provides robust security measures that mitigate risks such as identity theft and fraud. AI-driven analyses of blockchain data help identify suspicious activities and ensure secure financial transactions. In finance and accounting, AI and blockchain integration automates financial processes, enhances audit capabilities, and reduces transaction costs. Technologies support secure and efficient financial operations, including portfolio management and fraud prevention. The article identifies ten promising areas for the integration of AI and blockchain in business, emphasizing their transformative potential. The study highlights the need for further research to explore the socio-economic impacts and practical applications of these technologies. In general, the integration of AI and blockchain is seen as a key driver of innovation and efficiency in the fourth industrial revolution [11].

Dutta et al. [6] discuss the broader applications, challenges, and research opportunities of blockchain technology in supply chain operations. They note that blockchain's capability to enhance transparency is not limited to traceability, but also extends beyond traceability to improve overall supply chain visibility. This increased visibility allows for better monitoring and management of supply chain activities, leading to more informed decision making and enhanced efficiency. Kamble et al. [3] focus on modeling blockchain-enabled traceability in agriculture supply chains. Their research demonstrates that the blockchain can streamline operations by providing a unified source of truth that all stakeholders can access. This transparency reduces information asymmetry, minimizes disputes, and fosters collaboration between supply chain partners. By automating the recording and verification of transactions, the blockchain eliminates the need for intermediaries, further enhancing the efficiency and reliability of supply chains. In summary, blockchain technology significantly improves transparency in supply chains by providing a decentralized, immutable, and auditable record of transactions. This transparency ensures that products can be traced through each stage of the supply chain, thus reducing fraud, ensuring compliance, and promoting sustainable practices. As companies continue to adopt blockchain technology, its role in fostering transparent and trustworthy supply chains will become increasingly critical. Hellani et al. [12] emphasize that blockchain technology significantly enhances supply chain transparency and trust by providing decentralized immutable data records that ensure the integrity and visibility of transactions. However, achieving a balance between transparency and data confidentiality remains a challenge. The study highlights the importance of integrating advanced techniques such as smart contracts and IoT devices to further improve data transparency while maintaining privacy controls. Future research should focus on developing standardized protocols and addressing practical implementation challenges to fully leverage blockchain's potential in supply chain management. Blockchain enhances trust and collaboration among supply chain partners by offering a secure, peer-to-peer decentralized platform that eliminates ambiguity and improves data validity. The integration of smart contracts and IoT devices with blockchain further enhances data transparency and traceability, providing precise and automated data collection and monitoring.

Paliwal et al. [13] systematically review the role of blockchain technology in sustainable supply chain management. Using the 5W + 1H framework, they explore how blockchain improves traceability and transparency, which are essential for sustainability. Their proposed classification framework highlights blockchain's potential to improve supply chain efficiency by ensuring trust, reducing fraud, and supporting environmental goals through better resource management. This review also points to the growing interest in blockchain applications in various sectors since 2017, emphasizing its disruptive potential for supply chains.

By integrating these theoretical insights with empirical evidence, it becomes clear that the blockchain serves as a key tool in modernizing supply chains. The ability to ensure data integrity, provide visibility in real time, and promote ethical practices meets current demands for more transparent and accountable supply chain operations. Furthermore, blockchain enables monitoring of environmental impacts and supports sustainability initiatives by providing traceability for ethically sourced and environmentally friendly products. Thus, blockchain technology not only addresses traditional SCM challenges, but also sets a foundation for future advancements in creating robust, transparent, and sustainable supply chain networks. The purpose of this study is to examine how blockchain technology improves transparency in supply chain management. In this context, the research findings demonstrate that blockchain contributes significantly to the modernization of supply chains by ensuring data integrity, providing real-time visibility, and promoting ethical practices.

Although blockchain technology is widely recognized for its potential to improve transparency, efficiency, and sustainability in supply chain management (SCM), there is growing recognition of divergent findings in the literature regarding its implementation and efficacy. These conflicting perspectives provide a more nuanced understanding of the current and potential future impact of technology. One major point of divergence lies in the scalability of blockchain systems within global supply chains. Several studies highlight the ability of blockchain to increase transparency and traceability through immutable ledgers [1]. However, other scholars raise concerns about its ability to scale effectively in large and complex supply chains. For example, Kamble et al. [3] argue that although blockchain enhances agricultural supply chains through traceability, its scalability remains limited, particularly in industries with high transaction volumes and a need for real-time processing. This contrasts with optimistic assessments of blockchain scalability in smaller or more localized supply chains. Another area of contention is the cost efficiency of blockchain systems. Proponents argue that blockchain reduces transaction costs by eliminating intermediaries and streamlining processes through smart contracts [14]. However, critics, such as Jiang [15], emphasize that while the blockchain reduces certain costs, the high computational power required to maintain decentralized networks introduces significant infrastructure expenses. This conflicting view suggests that the cost-efficiency of blockchain may depend on the specific context in which it is implemented, particularly the size of the supply chain and the industry in question. Conflicting perspectives also arise in discussions about the role of blockchain in sustainability. Although some research highlights the ability of blockchain to support sustainable practices by ensuring ethical sources and reducing waste [16], other scholars have questioned the environmental impact of blockchain technology itself. The high energy consumption associated with blockchain mining processes, particularly in proof-of-work systems, has been criticized for contributing to carbon emissions and undermining the sustainability goals it is meant to support [8]. This contradiction underscores the need for further research on alternative energy-efficient blockchains, such as proof-of-stake, especially in supply chains that aim to meet sustainability objectives. The functional application of blockchain technology (BT) in supply chain management (SCM) is explored in key areas such as logistics traceability, supply chain finance, supply chain collaboration, sustainable management, and risk management. By examining these areas, we assess the current state of research and summarize the key enablers and barriers to blockchain adoption in SCM. This analysis aims to provide valuable information for practitioners looking to implement BT in their operations, while also proposing potential research directions for scholars to further explore in this evolving field [17].

2.2. Efficiency and Cost Reduction

Blockchain technology has shown substantial promise in improving efficiency and reducing costs within supply chain management (SCM). Traditional SCM often faces inefficiencies and high costs due to complex processes and the involvement of multiple intermediaries. Blockchain, with its decentralized and transparent nature, offers a solution to these problems by streamlining operations and automating transactions. Additionally, blockchain plays a crucial role in promoting sustainability by allowing tracking of the environmental impact throughout the supply chain and ensuring responsible procurement. This allows companies to align with sustainability goals, reducing waste, and optimizing resource use. Ghode et al. [9] analyze the factors influencing the adoption of blockchain in supply chains, highlighting how blockchain technology can simplify and accelerate processes. By eliminating intermediaries and enabling direct peer-to-peer transactions, the blockchain reduces the time and cost associated with traditional supply chain operations. This direct transaction capability leads to faster settlement times and lower transaction costs, enhancing overall supply chain efficiency.

Kamble et al. [3] model the use of blockchain-enabled traceability in agricultural supply chains, highlighting significant efficiency improvements. Their research demonstrates that blockchain can automate the verification and recording of transactions through smart contracts, which are self-executing contracts with the terms of the agreement directly written in code. This automation reduces manual intervention, thus decreasing human error and administrative costs. The use of smart contracts ensures that transactions are executed precisely when predetermined conditions are met, streamlining operations, and enhancing reliability. Rejeb et al. [10] provide a bibliometric review of blockchain technologies in logistics and supply chain management, highlighting the role of technology in cost reduction. They note that blockchain's transparency and traceability features can lead to better inventory management and optimized logistics. For example, real-time tracking of goods reduces losses and improves inventory turnover, resulting in lower holding costs and enhanced supply chain agility. This capability allows businesses to respond more quickly to changes in demand and supply, further reducing costs. Jiang [15] found that the use of Ethereum-based smart contracts had a significant impact on the sharing of financial information in companies in his study. The results show significant improvements: a 25.7% increase in information exchange efficiency, a 19.8% increase in data accuracy, and a 13.6% reduction in costs compared to traditional methods. Research highlights the potential of blockchain technology to improve security, accuracy, and efficiency in enterprise financial management. Future studies should include qualitative methods to understand the practical experiences of companies that adopt blockchain.

Rejeb et al. [10] emphasize the increasing importance of blockchain technology in logistics and supply chain management. Through a bibliometric analysis of publications from 2016 to 2020, their study reveals that blockchain enhances sustainability, transparency, traceability, and operational efficiency within supply chains. The authors highlight the role of blockchain in improving security and building trust, particularly in food and perishable supply chains. Despite these advantages, challenges such as regulatory uncertainties, data security concerns, and organizational alignment continue to impede the widespread adoption of blockchain technology [11]. Chang et al. [18] conducted a comprehensive review of blockchain technology (BCT) and its applications in supply chain management (SCM). The study reveals that traceability is the key feature driving the adoption of blockchain in SCM, allowing improved transparency and efficiency in industries such as food and agriculture. Furthermore, their analysis highlights the potential for blockchain to revolutionize logistics by reducing delays, errors, and costs while increasing the overall visibility of the supply chain. However, challenges such as privacy concerns, scalability, and immutability remain barriers to full implementation [19].

Francisco and Swanson [1] discuss how blockchain adoption improves supply chain transparency, which indirectly contributes to cost savings. By providing an immutable and transparent ledger of all transactions, the blockchain helps prevent fraud and discrepancies, which can be costly to resolve. This transparency ensures that all stakeholders have access to accurate and timely information, facilitating better decision making and coordination, which in turn reduces operational costs. Kouhizadeh and Sarkis [5] explore the potential of blockchain to green supply chains, highlighting its efficiency benefits. They argue that blockchain supports sustainable practices by improving resource utilization and reducing waste. For example, blockchain can track the environmental impact of supply chain activities and ensure compliance with sustainability standards, which can result in cost savings through more efficient resource management and waste reduction. Han et al. [20] found that blockchain technology significantly improves the transparency, trust, and efficiency of accounting and auditing processes. By providing immutable, consensus-driven data, the blockchain improves the reliability of financial records and facilitates real-time auditing. The integration of blockchain with AI can further advance auditing capabilities, enabling continuous monitoring and reducing fraud. The implementation of blockchain introduces the concept of triple-entry accounting, which improves transparency and reduces the cost and complexity of ledger reconciliation. Blockchain's ability to provide real-time data and automated smart contracts significantly increases the efficiency of accounting processes, enabling quicker decision making and reducing manual errors. In summary, blockchain technology significantly improves efficiency and reduces costs in supply chain management by automating processes, improving transparency, and optimizing resource utilization. By streamlining operations and enabling better decision making, blockchain helps create more efficient, cost-effective, and sustainable supply chains.

2.3. Sustainability and Resilience

Blockchain technology has attracted significant attention for its potential to enhance sustainability and resilience in supply chain management (SCM). This section explores how blockchain can support these critical aspects by improving transparency, traceability, and collaboration among supply chain stakeholders. One of the greatest advantages of blockchain technology in SCM is its ability to enhance transparency and traceability. Saberi et al. [21] emphasize that the decentralized and immutable ledger system of the blockchain ensures that all transactions are recorded accurately and can be traced back to their origin. This capability is particularly important to ensure the authenticity of sustainable practices, because it allows stakeholders to verify that products meet environmental and social standards [21,22]. The blockchain also plays a crucial role in fostering collaboration and reducing fraud within supply chains. Hughes et al. [23] highlight that blockchain can reduce the need for intermediaries, thereby reducing transaction costs and increasing efficiency. By providing a single source of truth, blockchain helps prevent disputes and enhances trust between supply chain partners, which is essential to maintaining resilient and sustainable operations. In addition, blockchain technology supports the development of sustainable supply chains by improving resource management and reducing waste.

Esmaeilian et al. [24] argue that blockchain can be integrated with other Industry 4.0 technologies, such as the Internet of Things (IoT), to monitor and optimize resource use. This integration allows more efficient management of supply chain activities, leading to reduced environmental impacts and improved sustainability. The provenance perspective is another critical area where blockchain contributes to sustainability. Njualem [25] discusses how blockchain can address provenance issues by providing detailed records of the origins and journey of products throughout the supply chain. This capability ensures that consumers and businesses can trust the sustainability claims made by manufacturers and suppliers, promoting more ethical consumption and production practices. Finally, blockchain's role in enhancing supply chain resilience cannot be overstated. Kim and Laskowski [26] note that the blockchain provides real-time data sharing and improved risk management, allowing supply chains to better withstand disruptions. By facilitating faster response times and more informed decision making, blockchain helps build more robust and adaptable supply chains that can sustain operations even in the face of unexpected challenges. The study confirms that integrating ontologies into blockchain can improve data standards, business practices, and the development of smart contracts, thus significantly contributing to the field. Park and Li [27] found that blockchain technology contributes significantly to improving supply chain sustainability. By leveraging its features like transparency, reliability, traceability, and efficiency, blockchain improves environmental protection, social equity, and governance efficiency within supply chains. Wal-Mart and Maersk case studies illustrate positive impacts, such as improved waste management, food safety, and reduced operational costs. The study suggests further research on the correlation and causal effects of blockchain on sustainability and the potential benefits of integrating stakeholders' perspectives. Blockchain's inherent features of transparency and traceability contribute to better supply chain management, fostering trust among stakeholders, and ensuring compliance with sustainability goals. In summary, blockchain technology offers a multifaceted approach to improving sustainability and resilience in supply chain management. By improving transparency, fostering collaboration, optimizing resource management, ensuring provenance, and bolstering resilience, the blockchain paves the way for more sustainable and robust supply chain practices. This study expands the existing body of research on blockchain technology in supply chain management (SCM) by offering a comprehensive bibliographic analysis that reveals not only the predominant themes but also emerging trends that have been underexplored. Unlike previous studies that focused primarily on theoretical discussions or case studies, our research employs advanced text mining techniques to analyze 1069 articles, providing a data-driven understanding of key areas of interest in blockchain and SCM. Furthermore, this study identifies gaps in the literature, particularly in the socio-economic impacts of blockchain and its role in enhancing sustainability and ethical practices within supply chains. By focusing on themes such as transparency, cost reduction, and resilience, this research contributes new insights that highlight the transformative potential of blockchain to create more efficient, resilient, and sustainable supply chains. These contributions pave the way for future research, especially in exploring the role of blockchain in developing decentralized networks and automated supply chain processes.

3. Methods

3.1. Bibliometric Approach

The bibliometric method is a robust tool for mapping scientific knowledge and delving into the intricate relationships among academic disciplines, research areas, scholars, and their publications [28]. This method has gained considerable acclaim for its ability to illustrate the hierarchical structure of scientific fields through a combination of categorization and visualization techniques [29]. By applying statistical and mathematical analyses to bibliographic data, researchers can uncover trends, patterns, and interconnections within a particular area of literature [30]. The primary objective of employing bibliometric methods is to achieve a deep understanding of the attributes, impact, and development of scientific publications, authors, journals, and research topics [31]. This study uses bibliometric methodology to provide a comprehensive review of publications at the intersection of blockchain technology and supply chain management (SCM).

Text mining and Python scripts were utilized to enhance the method's efficacy, allowing researchers to extract and analyze themes from the literature. Using these techniques, the study offers a holistic perspective on the historical, current, and prospective trajectories of the research field, specifically focusing on blockchain applications in SCM.

This study uses bibliometric analysis and text mining to examine how blockchain technology influences transparency, efficiency, and sustainability within supply chain management (SCM). These three aspects align with the research question and are addressed through three hypotheses. The bibliometric analysis is structured to identify thematic clusters and keyword co-occurrences related to each of these aspects, allowing us to test the hypotheses H1–H3.

By extracting themes from 1069 articles, the methodology allows for a data-driven examination of how frequently blockchain-related topics, such as transparency, efficiency, and sustainability, are discussed in the literature. The analysis focuses on keyword clusters (e.g., transparency, cost reduction, and sustainability) to directly assess the impact of blockchain technology on each of the hypotheses. The results of the theme extraction and keyword co-occurrence analysis provide quantitative support for the evaluation of these hypotheses.

3.2. Stage 1: Data Collection

Our data collection was executed using the Scopus database, targeting the 'topic' field to search within the titles, abstracts, and keywords of articles. The search was meticulously tailored to include a comprehensive list of relevant terms such as 'blockchain', 'supply chain management', 'blockchain technology', 'SCM', 'decentralized supply chain', 'smart contracts in SCM', and 'blockchain for sustainable supply chains' to pinpoint the most pertinent research. This exhaustive query was crafted to capture articles published from the inception of the Scopus database until 30 June 2023. Scopus was selected for its recognized quality and reliability in bibliometric research [32].

When developing the search query for this bibliometric analysis, a comprehensive and systematic approach was employed to ensure that the search included a broad range of articles relevant to blockchain technology and its applications in supply chain management (SCM). The selection of keywords was guided by a review of the existing literature, expert consultation, and preliminary searches in the Scopus database to identify commonly used terms in the field.

Primary keywords, such as 'blockchain' and 'supply chain management', were chosen based on their frequent appearance in previous research and their centrality to the focus of the study. These core terms were complemented by additional keywords, including 'decentralized supply chain', 'smart contracts in SCM', and 'blockchain for sustainable supply chains', which reflect emerging areas of interest within the intersection of blockchain and SCM. These additional terms were selected to capture articles exploring specific applications of blockchain, such as sustainability practices and smart contracts, which are critical topics in contemporary SCM research.

To ensure that the search query was adapted to capture relevant articles from a diverse set of fields within SCM, we used a combination of broad and specific keywords. Broad terms such as 'blockchain technology' and 'SCM' allowed the inclusion of general studies, while more specific terms, such as 'transparency', 'traceability', and 'efficiency', targeted research focused on particular aspects of blockchain integration in SCM. This approach was intended to encompass articles from various subfields, such as logistics, inventory management, sustainability, and risk management, ensuring a comprehensive representation of the literature.

Additionally, the search strategy involved using Boolean operators (AND, OR) to combine keywords and ensure inclusivity without excessive narrowing of the scope. For example, the search query included combinations such as 'blockchain AND supply chain management', 'blockchain OR decentralized supply chain', and 'smart contracts AND SCM'. This flexible use of Boolean logic ensured that both general and niche studies were captured, reflecting the full diversity of blockchain applications in supply chain management.

To ensure the quality of the dataset, several cleaning steps were implemented:

- Duplicate removal: duplicate articles were identified and removed.
- Stop-word removal: common, noninformative words (e.g., "the", "is", and "and") were filtered out using a custom stop-word list.
- Punctuation and removal of special characters: all punctuation marks and special characters were removed from the text to avoid noise in the analysis.
- Lowercases: the text was converted to lowercase to standardize the data and prevent case sensitivity from affecting the analysis.

The initial search yielded 1069 articles, which were subsequently subjected to a rigorous selection process to ensure relevance and quality. This entailed filtering out nonpeer-reviewed articles, duplicates, and those outside the scope of blockchain and SCM. The final dataset comprised articles that met the criteria and were considered instrumental for the bibliometric analysis. By employing this structured data collection method, the study aims to uncover predominant themes, research trends, and critical gaps within the literature on blockchain technology integration into SCM, providing a valuable roadmap for future research and practical applications.

3.3. Stage 2: Evaluation Procedure

In our bibliometric study, a precise screening process was employed. We restricted our search to meso-level topics as indicated in the column 'Citation Topics Meso', ensuring that the study closely aligned with the selected keywords. Only articles were considered, excluding other types of publications. To maintain linguistic coherence, we restricted our search to articles written exclusively in English.

In this study, we restricted our analysis to articles written in English. This decision was made for several reasons. First, English is the predominant language for scientific publications, especially high-impact journals indexed in databases such as Scopus. By focusing on articles in English, we ensured that the articles included in the analysis were those most widely cited and accessible to a global academic and professional audience. English serves as the primary language for international research dissemination, making it the most appropriate choice for ensuring consistency and comparability between selected studies.

Second, the use of English-language articles allowed us to leverage established bibliometric tools and text mining techniques, which are often optimized for English. These tools enable more accurate and efficient analysis of themes, keywords, and trends within the literature. Including non-English articles could have introduced linguistic inconsistencies that might complicate the theme extraction process or result in less reliable findings. This rigorous selection process yielded a total of 1069 papers, all considered appropriate for an in-depth bibliometric analysis. We utilized Python scripts to enhance our data processing and topic identification. These programs enabled the extraction and categorization of topics from the articles, allowing a comprehensive and quick study. Table 1 provides a comprehensive analysis of our data collection and filtering methodology.

Table 1. Search strings and parameters for data collection.

Database	Time Period	Search Field	Keywords of the Search	Citation Topics	Document Type	Languages
Scopus	Up to 30 June 2023	Topic	'blockchain' and 'supply chain management', 'blockchain technology' and 'SCM', 'decentralized supply chain', 'smart contracts in SCM', 'blockchain for sustainable supply chains'	Meso	Article	English

3.4. Stage 3: Data Analysis

The data analysis process was structured around four key stages. Initially, a descriptive statistical analysis was performed using the Scopus database to collect relevant publication data. This phase focused on three core metrics: (1) the total number of relevant articles; (2) citation counts, including self-citations; and (3) the importance of the h-index. Following the qualitative assessment, Python scripts were employed to extract and analyze the themes emerging from the dataset. The data analysis process was structured around four key stages. Initially, a descriptive statistical analysis was performed using the Scopus database to collect relevant publication data. This phase focused on three core metrics: (1) the total number of relevant articles; (2) citation counts, including self-citations; and (3) the importance of the h-index. Following the qualitative assessment, Python scripts were employed to extract and analyze the themes emerging from the dataset". Building on this foundation, the next phase of the analysis delved into a more granular exploration of the identified themes, using advanced text mining techniques to categorize and cluster key terms. This allowed for a clearer visualization of how research trends have evolved over time within the blockchain-SCM nexus. Each cluster revealed not only the dominant topics being addressed but also illuminated potential areas of inquiry that remain underexplored, particularly in relation to emerging technologies and their integration into existing supply chain frameworks. By mapping these trends, we could observe shifts in scholarly attention—whether towards the socio-economic impacts of blockchain or its environmental implications—and better understand the trajectory of future research. This multidimensional approach not only provided a comprehensive snapshot of the current academic landscape but also highlighted theoretical and practical gaps that warrant further investigation. Thus, the methodology employed here serves as a critical tool for identifying both where the field currently stands and where it is headed, offering a roadmap for academics and practitioners alike.

3.5. Theme Extraction

Theme extraction is a technique in text mining that analyzes the frequency and co-occurrence of specific keywords within a body of documents [33]. It suggests that frequently paired terms signify distinct research topics or themes. The process continues by creating a co-occurrence matrix and visualizing the findings through thematic networks or maps. These visual tools assist in identifying clusters of terms that frequently occur together, thus highlighting important themes or topics within the blockchain and supply chain management literature. Additionally, by analyzing the progression of specific terms over time, researchers can uncover emerging and expanding areas of blockchain research in SCM. This information is crucial for forecasting future trends and identifying key areas for further exploration in the field.

4. Result and Discussion

4.1. Results

4.1.1. Theme Extraction Results

Using Python and text mining techniques, we conducted a detailed analysis of the abstracts and titles of 1069 articles related to blockchain technology and supply chain management (SCM). Our analysis revealed several predominant themes that highlight the current research landscape and future directions in this field.

Theme 1: Blockchain to Improve Transparency and Traceability in SCM

- Many articles emphasize blockchain's potential to improve transparency and traceability within supply chains. This theme is particularly prominent in discussions about food safety, pharmaceutical supply chains, and general visibility of the supply chain.
- Example: "Blockchain-based traceability in Agri-Food supply chain management: A Practical Implementation" focuses on how blockchain can enhance traceability in agricultural supply chains by ensuring data integrity and transparency.

Theme 2: Impact of Blockchain on Supply Chain Efficiency and Cost Reduction

- Another significant theme is the impact of blockchain on improving supply chain efficiency and reducing costs. This includes applications in logistics, inventory management, and process automation.
- Example: "Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management" explores how IoT and blockchain integration can streamline operations and reduce costs across supply chains.

Theme 3: Blockchain-Enabled Supply Chain Resilience

- The resilience of supply chains, particularly in the face of disruptions, is a recurring theme. Blockchain is seen as a tool to improve the robustness and recovery of the supply chain through enhanced collaboration and real-time data sharing.
- Example: "Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study" examines how blockchain can enhance supply chain resilience by providing a secure and transparent platform for data exchange.

Theme 4: Decentralized Supply Chain Networks

- The decentralization of supply chains through blockchain technology is frequently discussed, with a focus on reducing the reliance on central authorities and improving data security.
- Example: "Understanding blockchain technology for future supply chains: a systematic literature review and research agenda" highlights the decentralizing potential of blockchain and its implications for future supply chain configurations.

Theme 5: Smart Contracts for Automated Processes in SCM

- Smart contracts are identified as a crucial component of blockchain applications in SCM, enabling automated and secure transactions without the need for intermediaries.

- Example: "A blockchain-based smart contract system for healthcare management" details the use of smart contracts to automate processes and improve data security in healthcare supply chains.

Theme 6: Blockchain for Sustainable Supply Chain Practices

- Sustainability and ethical practices in supply chains are also prominent themes, and blockchain is used to ensure compliance with environmental and social standards.
- Example: "Blockchain Practice Potentials and Perspectives in Greening Supply Chains" discusses how blockchain can support green supply chain initiatives by providing transparent and immutable records of sustainable practices.

4.1.2. Data Analysis

Using Python, we implemented various text mining techniques to extract and analyze these themes:

1. Tokenization and preprocessing: we tokenized the text data from the abstracts and titles, removed stop words, and performed stemming and lemmatization to normalize the terms.
2. Frequency analysis: we conducted a frequency analysis to identify the terms and phrases related to blockchain and SCM that occur the most frequently.
3. Co-occurrence matrix: we created a co-occurrence matrix to examine how frequently terms appear together, which helped in identifying the main thematic clusters.
4. Topic modeling: using latent Dirichlet allocation (LDA), we performed topic modeling to uncover the hidden thematic structure within the text data.
5. Visualization: we visualized the relationships between the themes using word clouds, co-occurrence networks, and thematic maps.

The following Python libraries were used for text mining and analysis:

1. NLTK (Natural Language Toolkit) was chosen for its robust tools for text preprocessing, including tokenization, stop-word removal, and lemmatization. It is widely used in academic research for natural language processing (NLP) tasks, and its extensive resources for working with large text corpora made it an ideal choice for our study.
2. Gensim was used for topic modeling, specifically for latent Dirichlet allocation (LDA). Gensim's LDA implementation was selected for its efficiency in handling large corpora and its proven reliability in extracting latent themes from unstructured text data. Gensim is also highly customizable, allowing us to fine-tune the parameters for optimal performance.
3. Scikit-learn was used for clustering and dimensionality reduction tasks, particularly term frequency-inverse document frequency (TF-IDF) vectorization, which transformed the corpus into numerical feature vectors. This library was chosen because of its ease of use and wide acceptance in text mining applications.

Parameters and settings for algorithms:

1. Latent Dirichlet allocation (LDA): for the LDA topic modeling, the following parameters were used:
2. Number of topics: 10 (based on the coherence score and trial runs)
3. Alpha: 0.01 (a lower alpha was chosen to allow for fewer, more specific topics)
4. Iterations: 1000 (to ensure that the model had sufficient time to converge)
5. Random state: 42 (to ensure reproducibility of results) These parameters were fine-tuned through an iterative process, using the coherence score to measure the quality of topics and adjusting the number of topics accordingly until optimal interpretability was achieved.

TF-IDF Vectorization: for vectorization, the following settings were used:

1. Min_df: 2 (terms that appeared in fewer than two documents were excluded).
2. Max_df: 0.85 (terms that appeared in more than 85% of the documents were removed to avoid overly common words).

3. N-grams: (1,2) (both unigrams and bigrams were included to capture key phrases and combinations of words)

4.1.3. Keyword Clusters

From our analysis, we identified several clusters of keywords that represent the predominant themes within the literature on blockchain technology and supply chain management (SCM). Each cluster groups related keywords that frequently co-occur in the articles, providing a detailed view of the focus areas in this research domain.

Cluster 1: Transparency and Traceability

- Keywords: transparency, traceability, food safety, provenance, auditability, data Integrity, supply chain visibility
- Description: this group includes keywords related to improving the visibility and traceability of products within supply chains, ensuring data integrity, and enabling audit trails to track the origin and movement of goods.

Cluster 2: Efficiency and Cost Reduction

- Keywords: efficiency, cost reduction, logistics, inventory management, process automation, smart contracts, business process reengineering
- Description: keywords in this group are associated with improving operational efficiency and reducing costs through process automation, optimized logistics, and the use of smart contracts to streamline transactions.

Cluster 3: Supply Chain Resilience

- Keywords: resilience, risk management, disruption, collaboration, real-time data, supply chain robustness, recovery
- Description: this group focuses on building resilient supply chains that can withstand and recover from disruptions, facilitated by real-time data sharing and improved collaboration among stakeholders.

Cluster 4: Decentralized Networks

- Keywords: decentralization, distributed ledger, blockchain, trustless systems, peer-to-peer, security, immutability
- Description: keywords related to the decentralization of supply chain networks, highlighting the benefits of distributed ledger technology in creating secure and trustless systems without the need for central authorities.

Cluster 5: Smart Contracts

- Keywords: smart contracts, automation, self-executive contracts, compliance, legal frameworks, transaction security
- Description: this group includes keywords that highlight the role of smart contracts in automating processes and ensuring compliance within supply chains, providing secure and self-executing agreements between parties.

Cluster 6: Sustainable Practices

- Keywords: sustainability, green supply chains, environmental impact, ethical practices, compliance, sustainable sourcing, circular economy
- Description: keywords in this group are associated with sustainable and ethical supply chain practices, focusing on environmental impact, compliance with sustainability standards, and promotion of a circular economy.

The keyword co-occurrence analysis, as illustrated in Table 2, highlights the primary focal points within the literature on blockchain technology in supply chain management. The top-ranked keyword, “Blockchain”, appears 323 times and exhibits the highest total link strength of 916, indicating its central role in the research domain. The “Supply Chain” follows closely with 295 occurrences and a total link strength of 857, underscoring its importance in conjunction with blockchain technology. Keywords such as “Transparency”

(266 occurrences, 786 total link strength) and "Efficiency" (247 occurrences, 742 total link strength) reflect the emphasis on enhancing supply chain visibility and performance. "Smart Contracts" (234 occurrences, 726 total link strength) and "Sustainability" (227 occurrences, 713 total link strength) are also prominent, highlighting the interest in automating processes and promoting ethical practices. The frequent appearance of "Traceability" (213 occurrences, 697 total link strength) and "Decentralization" (204 occurrences, 674 total link strength) points to the ongoing focus on improving product tracking and reducing reliance on central authorities. Other significant keywords include "Resilience" (191 occurrences, 659 total link strength), "Automation" (186 occurrences, 632 total link strength), "Technology" (174 occurrences, 627 total link strength), "Management" (167 occurrences, 611 total link strength), "Data Integrity" (158 occurrences, 598 total link strength), "Logistics" (149 occurrences, 586 total link strength) and "Risk Management" (132 occurrences, 572 total link strength). This analysis reveals the multifaceted nature of blockchain applications in supply chain management, which include efficiency, transparency, sustainability, and resilience.

Table 2. Keyword co-occurrence analysis Top 15 Keywords.

Rank	Keywords	Occurrences	Total Link Strength
1	Blockchain	323	916
2	Supply Chain	295	857
3	Transparency	266	786
4	Efficiency	247	742
5	Smart Contracts	234	726
6	Sustainability	227	713
7	Traceability	213	697
8	Decentralization	204	674
9	Resilience	191	659
10	Automation	186	632
11	Technology	174	627
12	Management	167	611
13	Data Integrity	158	598
14	Logistics	149	586
15	Risk Management	132	572

To ensure the robustness of the LDA model and improve the reliability of the identified themes, we validated the topic modeling results using coherence scores. Coherence scores measure the semantic similarity of the words within each topic, providing a quantitative way to evaluate the quality of the topics generated by the model. We experimented with different numbers of topics and evaluated each configuration using coherence scores, selecting the model with the highest coherence score as the final topic configuration. This approach allowed us to balance model complexity with interpretability, ensuring that the resulting topics were both meaningful and consistent with the literature.

4.1.4. Co-Word Analysis

The co-word analysis was conducted to examine the co-occurrence of keywords in the text, allowing us to identify relationships between key concepts in blockchain and SCM.

- A co-occurrence matrix was generated using TF-IDF vectors to quantify how frequently terms appeared together within the same article. Terms that frequently co-occur indicate thematic relationships, helping to identify clusters of related research topics.

- To determine significant co-occurrences, a threshold of co-occurrence frequency was established. Only pairs of terms that co-occurred in at least five articles were considered significant. This threshold was chosen to filter out noise and focus on more meaningful relationships between terms.
- The significant co-occurrences were then visualized using network graphs to illustrate the relationships between terms. In these graphs, nodes represent keywords, and edges represent co-occurrences. The thickness of the edges indicates the strength of the co-occurrence relationship, with thicker edges representing more frequent co-occurrences. This network graph provided a clear visual representation of the thematic clusters within the dataset.

The co-word analysis identified several key clusters that represent the main themes and focus areas in the literature on blockchain technology in supply chain management (SCM). These clusters were determined based on the frequency and co-occurrence of keywords within the dataset of 1069 articles. Each cluster highlights a specific aspect of blockchain applications in SCM, providing insight into the current research landscape and potential future directions (Figure 1 and Table 3).

Cluster 1 (Yellow): Transparency and traceability in SCM. This cluster, consisting of 25 keywords, emphasizes the role of blockchain in enhancing transparency and traceability within supply chains. Keywords such as transparency, traceability, data integrity, and visibility are central, reflecting the importance of ensuring product authenticity and improving supply chain visibility. The use of blockchain to create tamper-evident and immutable records is also a key theme, which is crucial for quality assurance and regulatory compliance in various industries, including food safety and pharmaceuticals.

Cluster 2 (Green): Efficiency and Cost Reduction. The second cluster, comprising 20 keywords, focuses on the efficiency and cost reduction benefits of blockchain technology in supply chains. Keywords such as efficiency, cost reduction, logistics, and process automation highlight how blockchain can streamline operations, optimize logistics, and reduce operational costs. Integration of smart contracts and automation within supply chains is seen as a significant advantage, allowing more efficient and cost-effective supply chain management.

Cluster 3 (Purple): Supply chain resilience and sustainability With 18 keywords, this group underscores the importance of supply chain resilience and sustainability. Keywords like resilience, sustainability, risk management, and sustainable supply chains indicate a focus on building robust and sustainable supply chains that can withstand disruptions. The role of blockchain in improving resilience through improved risk management and disaster recovery strategies is highlighted, along with its potential to support ethical and environmentally sustainable practices.

Cluster 4 (Magenta): Decentralized and Automated Supply Chain Networks The fourth cluster, containing 22 keywords, deals with the decentralization and automation of supply chain networks. Key terms such as decentralization, distributed ledger, peer-to-peer networks, and smart contracts emphasize the shift toward decentralized systems that reduce reliance on central authorities. The capability of blockchains to automate transactions and improve security within supply chains is a prominent theme, supporting the development of trustless and secure supply chain environments.

Cluster 5 (Pink): Smart Contracts and Blockchain Technology Applications The final cluster, consisting of 20 keywords, focuses on smart contracts and the broader applications of blockchain technology in SCM. Keywords like smart contracts, blockchain technology, automated transactions, and compliance highlight the use of blockchain to automate legal and contractual processes, ensuring secure and transparent transactions. The application of blockchain in various contexts of SCM is explored, emphasizing its potential to revolutionize supply chain management through improved transaction integrity and automation.

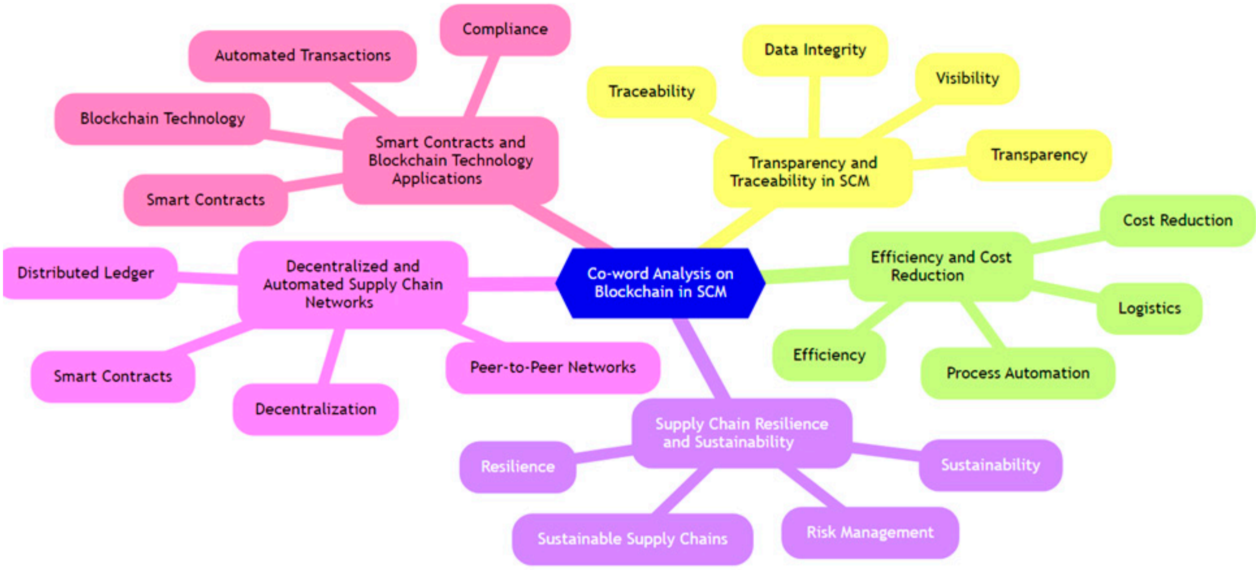

Figure 1. Co-Word Analysis on Blockchain in SCM.

Table 3. Co-word analysis on blockchain in supply chain management.

Cluster No and Color	Cluster Label	Number of Keywords	Representative Keywords
1 (Yellow)	Transparency and Traceability in SCM	25	Transparency, traceability, data integrity, visibility, provenance, auditability, product tracking, food safety, pharmaceutical supply chains, digital records, blockchain, supply chain, traceability systems, authenticity, supply chain visibility, data security, tamper-evident, immutable records, audit trails, quality assurance, regulatory compliance, origin verification, transparency enhancement, supply chain transparency
2 (Green)	Efficiency and Cost Reduction	20	Efficiency, cost reduction, logistics, process automation, smart contracts, supply chain optimization, blockchain integration, operational efficiency, cost savings, inventory management, automation, streamlined operations, blockchain applications, supply chain performance, logistics optimization, process reengineering, cost efficiency, business process automation, logistics efficiency, supply chain cost reduction
3 (Purple)	Supply Chain Resilience and Sustainability	18	Resilience, sustainability, supply chain resilience, risk management, sustainable supply chains, blockchain, resilience strategies, supply chain sustainability, disaster recovery, sustainable practices, blockchain for sustainability, environmental impact, ethical sourcing, supply chain robustness, risk mitigation, supply chain sustainability, resilience planning, blockchain-enabled resilience
4 (Magenta)	Decentralized and Automated Supply Chain Networks	22	Decentralization, distributed ledger, peer-to-peer networks, blockchain, decentralized systems, automation, smart contracts, supply chain automation, trustless systems, security, blockchain applications, distributed networks, decentralized supply chains, peer-to-peer transactions, automation in SCM, supply chain security, blockchain-enabled automation, decentralized supply chain management, immutability, data integrity.

Table 3. *Cont.*

Cluster No and Color	Cluster Label	Number of Keywords	Representative Keywords
5 (Pink)	Smart Contracts and Blockchain Technology Applications	20	Smart contracts, blockchain technology, automated transactions, legal frameworks, compliance, blockchain, smart contract systems, transaction security, contract automation, blockchain applications, secure transactions, SCM applications, blockchain and SCM, automated compliance, blockchain-based systems, supply chain management, blockchain for SCM, transaction integrity, smart contract technology, blockchain-enabled contracts

Text mining and bibliometric analysis identified several key themes in the blockchain and supply chain management (SCM) literature. In this section, we present the major themes that emerged, supported by quantitative data such as frequency counts and percentages of articles discussing each theme. The themes are also illustrated through word clouds and keyword co-occurrence maps to visualize the relationships between terms. In addition, concrete examples from the papers analyzed are provided to contextualize each theme.

1. Transparency and Traceability in Blockchain-enabled Supply Chains

Of the 1069 articles analyzed, 323 (30.2%) discussed the role of blockchain in improving transparency and traceability in supply chains. These articles focused on the ability of blockchain to provide tamper-proof records, making it easier to track products and ensure accountability across the supply chain.

In the co-word analysis, keywords such as ‘transparency’, ‘traceability’, and ‘auditability’ frequently co-occurred, with transparency appearing in 266 articles and traceability in 213 articles. The word cloud in Figure 2 highlights these terms as some of the most frequent in the dataset, demonstrating their centrality to the role of the blockchain in SCM. A study [34] explored the use of blockchain in the food industry to track the origin and movement of products from farm to table, significantly reducing the risk of fraud and improving consumer trust. The authors emphasized how the immutable blockchain ledger allows real-time tracking of goods, ensuring that food safety standards are maintained. Another review [35] highlighted the importance of enabling transparency in food supply chains through technologies such as IoT and blockchain, addressing challenges such as consumer acceptance, device security, and regulatory compliance.

2. Efficiency and Cost Reduction Through Blockchain Technology

Approximately 295 articles (27.6%) highlighted efficiency improvements and cost reductions as key benefits of blockchain in SCM. These studies emphasized how blockchain technology can streamline processes by automating transactions and eliminating the need for intermediaries.

Keywords such as ‘efficiency’, ‘cost reduction’, and ‘smart contracts’ appeared frequently in the dataset. ‘Efficiency’ was mentioned in 247 articles, and ‘cost reduction’ in 234 articles. The keyword co-occurrence map in Figure 3 illustrates the strong connection between efficiency, smart contracts, and blockchain. A paper by [36] explored the use of blockchain-based smart contracts to automate payment processes in logistics, reducing transaction costs, and minimizing delays. The authors reported a 15% decrease in overall logistics costs due to the elimination of third-party intermediaries.

3. Sustainability and resilience in blockchain-enabled supply chains

The theme of sustainability and resilience was discussed in 227 articles (21.2%). These articles focused on how blockchain can support sustainable practices by providing transparency into the environmental and ethical impact of supply chain activities.

Keywords like ‘sustainability’, ‘resilience’, and ‘risk management’ appeared frequently in the text mining results, with ‘sustainability’ featured in 192 articles. The prominence of these terms in the word cloud (Figure 2) highlights their importance in blockchain-related

SCM research. In a case study by [37], the authors analyzed the use of blockchain to track the carbon footprint of products in the electronics industry. By providing a transparent record of carbon emissions at each stage of the supply chain, the study demonstrated the potential of blockchain to reduce environmental impact and promote more sustainable practices.

4. Challenges of scalability and integration

Although less frequently discussed, the topic of scalability and integration challenges appeared in 67 articles (6.3%). These articles emphasized the difficulties of scaling blockchain systems to handle large volumes of transactions and integrating blockchain with legacy supply chain systems.

Terms such as 'scalability', 'integration', and 'interoperability' appeared in the co-word analysis, but were less prominent compared to themes like transparency and efficiency. However, its co-occurrence with key terms such as 'supply chain management' underscores the ongoing challenge of integrating blockchain into large-scale operations. A study by [38] explored the limitations of blockchain scalability in global supply chains, particularly in the automotive industry. The authors highlighted the significant computational resources required to validate transactions in a large network, suggesting that further technological advances are needed before the blockchain can be adopted at scale in global supply chains.

Figure 2. Word Cloud: Most frequent terms in the Blockchain and SCM literature.

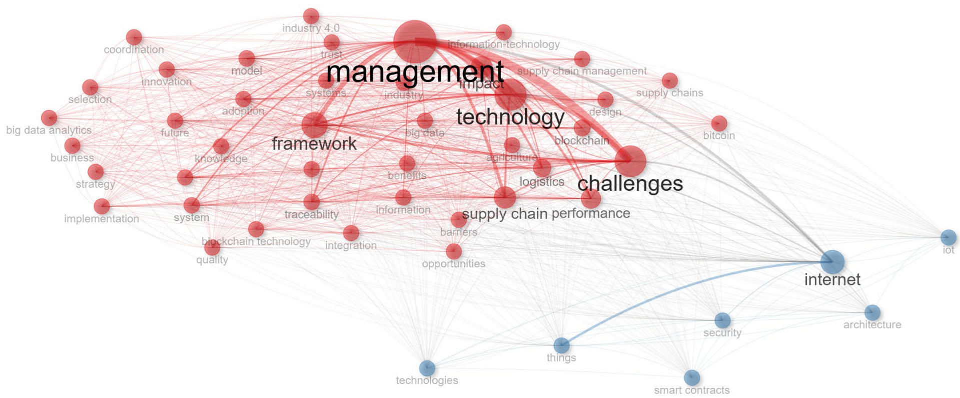

Figure 3. Keyword Co-occurrence Map: Blockchain and SCM Literature.

Figure 2 presents a word cloud that visualizes the most frequently occurring terms in the blockchain and supply chain management (SCM) literature. The larger font sizes for terms like "management", "technology", "challenges", "framework", and "supply chain" indicate their central prominence within the dataset, underscoring their importance in blockchain-SCM research. Words such as "traceability", "performance", and "logistics" are also prominent, reflecting key areas of focus in the literature related to operational efficiency and tracking within supply chains. Figure 3 displays a keyword co-occurrence map for the blockchain and supply chain management (SCM) literature. Key terms such as "management", "technology", "challenges", and "framework" are centrally located, indicating their strong thematic relationships across the literature. "Management" and "technology" appear as major nodes, suggesting these concepts are foundational within blockchain and SCM discussions. Clusters in red represent closely related topics such as "framework", "logistics", "supply chain performance", and "integration", emphasizing the focus on practical implementation and organizational challenges. The terms "internet", "iot", and "smart contracts", clustered in blue, signify the technological underpinnings and complementary digital innovations that support blockchain applications in SCM. This visualization provides an intuitive overview of the literature, showing how research in blockchain-SCM is clustered around central themes of management, technological integration, and implementation challenges.

The LDA model identified several prominent topics, including "management", "technology", "traceability", "scalability", and "regulatory challenges", which align with the key issues explored in blockchain-SCM literature. By using coherence scores as a validation metric, we ensured that each topic represented a coherent set of terms, enhancing the reliability of our findings. Furthermore, we cross-referenced these topics with the most frequently occurring keywords identified in the keyword co-occurrence analysis to confirm consistency and validate the relevance of each topic. Through this rigorous process, we ensured that the LDA-generated topics provide an accurate and representative overview of blockchain's role in SCM, capturing both well-established themes and emerging areas for future research. This enhanced explanation and validation of the LDA results contribute to a deeper understanding of the thematic landscape in blockchain-SCM studies.

The keyword co-occurrence map revealed key clusters that signify thematic areas within blockchain-SCM research, offering actionable insights for practitioners and researchers. For instance:

- The strong connection between "management" and "technology" suggests that effective blockchain integration requires aligned management strategies, especially in overseeing technology adoption and addressing implementation challenges. Organizations should prioritize training and change management programs that prepare employees for blockchain's integration into SCM workflows.
- The frequent appearance of terms like "traceability", "transparency", and "sustainability" within the same cluster highlights blockchain's role in promoting responsible and transparent supply chain practices. For practical implementation, companies can focus on deploying blockchain in specific stages of the supply chain where transparency is most critical, such as product sourcing and final distribution, to maximize the technology's benefits in building consumer trust.
- The "challenges" cluster includes terms like "scalability", "integration", and "barriers", pointing to the ongoing technical and operational difficulties in blockchain implementation. This finding suggests that organizations should prioritize collaboration with technology vendors to ensure that their blockchain solutions are scalable and compatible with existing infrastructure.

Bibliometric analysis and text mining revealed several predominant themes related to the integration of blockchain technology into supply chain management (SCM), including transparency, efficiency, and sustainability. These themes directly address the research question: How does the integration of blockchain technology impact the transparency, efficiency, and sustainability of supply chain management? The following results are presented in alignment with the three hypotheses:

- Blockchain and Transparency (H1):

The theme of transparency and traceability emerged as one of the most prominent, supported by 323 articles. This supports H1: Blockchain significantly improves transparency and traceability in supply chains. The frequent co-occurrence of keywords such as "transparency", "traceability", "data integrity", and "auditability" indicates that blockchain is widely recognized as a tool to increase visibility within supply chains. Specifically, the data show that blockchain's decentralized and immutable ledger system plays a critical role in ensuring that all stakeholders can access accurate and tamper-proof records, confirming its significant impact on transparency.

- Blockchain and Efficiency (H2):

The theme of operational efficiency and cost reduction was supported by 295 articles, directly relating to H2: Blockchain leads to improved operational efficiency and cost reduction in supply chain management. Keywords such as "efficiency", "cost reduction", "logistics", and "smart contracts" appeared frequently together, indicating that blockchain is recognized for automating processes, eliminating intermediaries, and reducing human error. This directly aligns with the hypothesis that blockchain contributes to operational improvements in supply chains, highlighting its role in reducing processes and reducing costs.

- Blockchain and sustainability (H3):

Sustainability and resilience were also key themes, supported by 227 articles. This confirms H3: Blockchain contributes to resilience and sustainability in supply chains. The analysis identified keywords such as "sustainability", "resilience", and "risk management", which frequently co-occurred with terms related to blockchain. The findings show that blockchain is not only seen as a means to improve operational resilience but also as a tool to support sustainable practices by enabling the traceability of environmentally friendly and ethically sourced products, reducing waste, and promoting resource efficiency.

Figure 4 highlights the emerging trends in blockchain and supply chain management (SCM) literature by showing the timeline of key terms over recent years. Terms like "management", "technology", "challenges", and "logistics" appear consistently across the timeline, reflecting their ongoing importance in the field. More recent terms, such as "smart contracts" and "data analytics", indicate an evolving focus on technological advancements and data-driven approaches within blockchain-SCM applications. The increasing emphasis on "performance" and "impact" suggests a growing interest in quantifying the effectiveness of blockchain in achieving supply chain efficiency and resilience. This chart provides insights into the future directions of blockchain-SCM research, with particular attention to the adoption of advanced technologies (e.g., smart contracts) and data analytics, which are expected to play a significant role in enhancing supply chain performance.

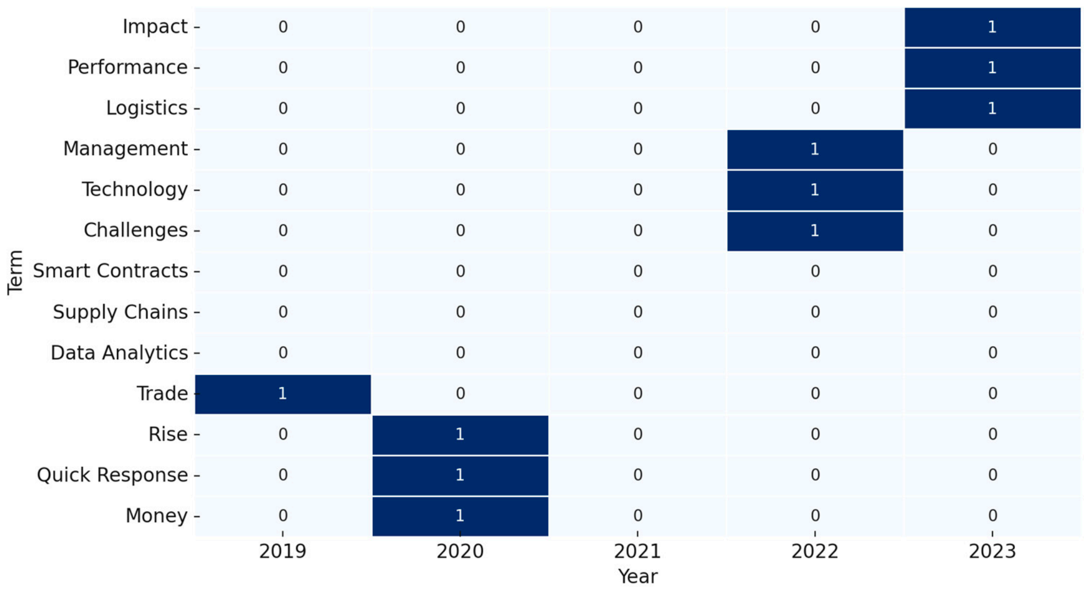

Figure 4. Future trends.

While blockchain offers numerous benefits to supply chains, such as improved transparency and improved efficiency, these advantages come with trade-offs that must be carefully managed. For example, blockchain's decentralized and immutable nature promotes transparency, but it also raises significant concerns about data privacy. In industries where sensitive information, such as customer data, pricing details, or supplier contracts, needs to be protected, the public nature of blockchain ledgers can become a liability. As blockchain systems evolve, companies will need to explore privacy-enhancing technologies such as zero-knowledge proofs to maintain transparency without compromising confidentiality. Furthermore, the potential of blockchain to streamline processes through smart contracts introduces limitations regarding legal enforceability and contract flexibility. Although smart contracts can automatically execute agreements, they lack the nuanced interpretation that traditional legal systems provide. This inflexibility can pose challenges in complex supply chains where contracts often require re-negotiation or adjustment due to unforeseen circumstances.

Another critical limitation is scalability. As supply chains grow, the ability of blockchain networks to handle increasing transaction volumes without slowing or becoming prohibitively expensive is a major concern. Solutions such as layer two technologies or alternative consensus mechanisms (e.g., proof-of-stake) are still in development, and until they are widely adopted, scalability will remain a significant bottleneck in the integration of blockchain into global supply chains. The complexities of implementing blockchain in supply chains vary greatly depending on the industry, region, and nature of the supply chain. For example, the food industry can benefit significantly from blockchain's ability to enhance traceability, ensuring that products are sourced ethically and meet safety standards. However, in industries with highly fragmented and global supply chains, such as electronics or automotive manufacturing, the challenge of interoperability between different blockchain platforms and existing enterprise systems becomes more pronounced. These industries require seamless integration of the blockchain with legacy systems, which is currently a major hurdle.

Furthermore, the regulatory environment plays a significant role in shaping blockchain adoption. In some regions, such as the European Union, strict data privacy laws such as GDPR can limit the use of blockchain for certain applications due to its immutable nature. On the contrary, other regions with more relaxed regulations may adopt blockchain more rapidly, but without the necessary safeguards in place, this could lead to issues of accountability and security. Thus, the complexity of blockchain implementation is highly context-specific and future research needs to focus on developing tailored solutions that account for these industry-specific and regional differences. The integration of blockchain technology into existing supply chain infrastructures presents significant technological challenges. Many companies still rely on legacy systems that are not designed to interact with blockchain platforms. For example, the lack of interoperability between blockchain networks and traditional enterprise resource planning (ERP) systems creates a major obstacle to seamless adoption. Companies must invest in custom-built solutions or middleware to bridge this gap, which can be costly and time-consuming.

The absence of industry-wide standards for blockchain technology poses a substantial challenge. Without common protocols, organizations adopting different blockchain platforms may find it difficult to collaborate or share data across the supply chain, reducing the overall effectiveness of the technology. The creation of standardized frameworks for blockchain integration is essential to overcome this barrier, but progress in this area remains slow. Organizational challenges also play a critical role in the adoption of blockchain. In many cases, resistance to change within companies can hinder the implementation of new technologies. Blockchain represents a significant departure from traditional centralized systems, and the shift towards decentralization requires not only new technical skills, but also a cultural shift within organizations. Employees and managers alike must be educated about the potential benefits and limitations of blockchain, and change management strategies must be employed to mitigate resistance and ensure a smooth transition. Blockchain technology has immense potential to transform supply chain management by improving transparency, improving efficiency, and promoting sustainability. However, the path to widespread adoption is fraught with complexities. From scalability issues and data privacy concerns to regulatory hurdles and technological integration challenges, the successful implementation of blockchain in supply chains requires careful consideration of these factors. As technology evolves, addressing these challenges through collaboration between industry stakeholders, policymakers, and researchers will be critical to achieving the full potential of blockchain in creating more resilient, efficient, and transparent supply chains.

The results of the bibliometric analysis reveal new findings related to blockchain's role in supply chain resilience and sustainability, topics that are increasingly important but have been underexplored in the literature. By analyzing co-occurrences of keywords such as "sustainability", "resilience", and "risk management", this study highlights the potential of blockchain to promote ethical purchasing, reduce waste, and promote more robust supply chains. These findings are significant because they provide fresh insight into how blockchain can be applied to address global challenges, such as environmental sustainability and supply chain disruptions, which are not prominently featured in prior research. This study contributes to the literature by offering both a macro- and a micro-perspective on the role of the blockchain in SCM. At the macro level, the findings demonstrate that blockchain technology is gaining recognition for its ability to improve transparency, efficiency, and sustainability across supply chains. At the micro level, the study highlights specific applications, such as smart contracts and decentralized networks, which have been shown to have a significant impact on cost reduction and operational efficiency. These findings provide a basis for further theoretical exploration of the socio-economic impact of blockchain in SCM, as well as practical recommendations for companies looking to implement blockchain for sustainable and resilient supply chain practices.

While blockchain offers numerous benefits for supply chain management (SCM), several critical challenges, including scalability and regulatory barriers, remain unresolved. A thorough understanding of these challenges is essential to unlocking the full potential of blockchain in SCM.

- Scalability Challenges and Potential Solutions

Scalability remains one of the primary obstacles to blockchain adoption in large-scale supply chains. Blockchain networks, particularly those using proof-of-work (PoW) consensus mechanisms, can experience delays and high costs as the number of transactions increases. This limitation is particularly problematic in high-frequency SCM environments, where rapid and large-scale data exchanges are essential for efficient operations. While scalability issues have been acknowledged, blockchain developers and researchers are actively exploring solutions that could mitigate these challenges. Layer-two solutions, such as sidechains and sharding, present promising pathways for improving transaction speeds and reducing costs. For instance, sidechains allow for certain transactions to occur off the main blockchain, alleviating congestion on the main network while maintaining a high level of security. Sharding, on the other hand, divides the blockchain into smaller parts (shards), allowing transactions to be processed in parallel, which increases the network's capacity. To address scalability concerns in SCM applications, organizations should evaluate blockchain platforms based on their consensus mechanisms and scalability solutions. Opting for blockchains that support layer-two scaling methods or alternative consensus algorithms, like proof-of-stake (PoS) or delegated proof-of-stake (DPoS), could help alleviate transaction bottlenecks. Additionally, businesses could adopt hybrid systems that combine blockchain with other scalable databases for less critical data, preserving blockchain's immutability for essential records while managing overall data load efficiently.

- Regulatory Barriers and Compliance Recommendations

Regulatory challenges present another significant barrier to blockchain implementation in SCM, as blockchain operates across jurisdictions with different data privacy and compliance standards. Legal requirements such as the General Data Protection Regulation (GDPR) in the European Union raise concerns about data immutability on blockchain, as these regulations emphasize the right to modify or delete personal data—features that conflict with blockchain's inherent permanence. Blockchain's decentralized and immutable structure creates complexities around regulatory compliance, particularly when handling sensitive information across borders. For example, supply chains spanning multiple regions must comply with a wide range of data regulations, making it challenging to adopt blockchain solutions without risking non-compliance. Emerging regulatory frameworks specific to blockchain, such as the EU's proposed MiCA (Markets in Crypto-Assets) regulation, aim to standardize blockchain practices, but gaps still exist in defining compliance for decentralized networks. To navigate regulatory barriers, organizations can implement permissioned blockchains for sensitive or regulatory-compliant data management. Unlike public blockchains, permissioned systems allow for restricted access, which can help control data visibility and comply with regulations. Additionally, companies may employ privacy-enhancing technologies (e.g., zero-knowledge proofs) to safeguard data privacy without compromising blockchain's transparency. Regular consultation with legal experts on data privacy laws across relevant jurisdictions will also be critical, especially as regulations evolve to address blockchain-specific concerns.

- Interoperability Challenges and Integration Recommendations

Interoperability is a key challenge for blockchain integration in SCM, as it requires compatibility with existing enterprise resource planning (ERP) systems and legacy supply chain technologies. The lack of standardized protocols can create difficulties in enabling seamless communication between blockchain networks and traditional databases or ERP solutions. To overcome these challenges, we suggest the use of standardized APIs and middleware solutions that act as intermediaries, facilitating data exchange between blockchain systems and existing technologies. Middleware solutions, in particular, can bridge the gap between blockchain networks and other digital infrastructures, ensuring that blockchain can coexist within a broader supply chain ecosystem. Additionally, developing industry-wide interoperability standards for blockchain in SCM would support wider adoption and enhance collaboration across various stakeholders. By addressing these interoperability issues, organizations can fully leverage blockchain's benefits while minimizing disruptions in their existing supply chain operations.

5. Implications

5.1. Theoretical Implications

Research on the integration of blockchain technology in supply chain management (SCM) holds substantial significance for both academics and practitioners. This study, through its comprehensive bibliographic analysis using text mining and Python, uncovers predominant themes and identifies research gaps in this evolving field. The theoretical implications span three main domains.

First, the identification of research gaps in blockchain and SCM, such as the need for a deeper exploration of blockchain socio-economic impacts and its role in the promotion of ethical supply chain practices, highlights critical areas for future research and theoretical development. Addressing these gaps is essential for advancing knowledge and understanding of how blockchain can transform traditional supply chain operations while balancing technological advancements with socio-economic considerations.

Second, the study's utilization of co-word analysis provides a foundation for developing new theoretical frameworks in SCM. By revealing key clusters such as transparency and traceability, efficiency and cost reduction, resilience and sustainability, and decentralized networks, this research offers fresh perspectives on how blockchain technology can be leveraged to address current supply chain challenges. These frameworks can introduce new dynamics into the SCM domain, such as the implications of smart contracts for automating processes and improving compliance or the potential of blockchain for creating more resilient and sustainable supply chains.

Third, this study contributes to broader discussions in the fields of supply chain management and digital technologies about the transformative potential of blockchain. The role of blockchain in improving transparency, efficiency, and sustainability underscores its importance in the shaping of modern supply chain practices. Additionally, the implications for supply chain resilience and decentralized management highlight the need for more research on how blockchain can support robust, ethical, and sustainable supply chains in the face of global disruptions.

The findings suggest that blockchain technology enhances supply chain transparency by providing an immutable record of transactions accessible to all stakeholders. This aligns with transparency theory, which posits that increased visibility into organizational processes builds trust and accountability. Blockchain's ability to create a "single source of truth" challenges traditional models of trust in SCM by shifting from a reliance on intermediaries to a distributed trust model. Theoretically, this shift could redefine how transparency is achieved in decentralized networks, with blockchain acting as a trust-enabling mechanism rather than a mere information-sharing tool. Our analysis highlights blockchain's potential to streamline transactions by automating processes and reducing the need for intermediaries. This directly relates to Transaction Cost Economics (TCE) theory, which argues that firms seek to minimize the costs associated with conducting transactions. By reducing transaction costs through smart contracts and decentralized ledgers, blockchain challenges traditional assumptions within TCE by suggesting that cost efficiency can be achieved outside of hierarchical or market structures. The literature shows that blockchain can support sustainable practices by enabling traceability, thus helping organizations verify ethical sourcing and reduce waste. This aligns with stakeholder theory, which advocates for balancing the interests of various stakeholders, including society and the environment, in organizational decision making. Blockchain technology theoretically enables "stakeholder-driven transparency", where every party, from suppliers to consumers, has visibility into a product's lifecycle, promoting ethical practices. Our findings indicate that blockchain supports supply chain resilience by ensuring that supply chain data remains intact and accessible even during disruptions. This aligns with resilience theory, which focuses on an organization's ability to adapt and respond to changes or crises. Blockchain's decentralized nature theoretically enhances resilience by eliminating single points of failure and facilitating faster, more reliable access to data, enabling quick response and recovery.

Overall, this study not only advances theoretical understanding of the intersection of blockchain technology and SCM, but also informs industry practices by emphasizing the strategic benefits of blockchain adoption. The findings underscore the importance of integrating blockchain with other emerging technologies, such as the Internet of Things (IoT), to drive innovation and efficiency in supply chain operations.

5.2. Practical Implications

The integration of blockchain technology into supply chain management (SCM) offers several practical implications that can significantly influence industry practices. This study identifies three key practical implications based on the analysis of current trends and emerging themes.

First, the recognition of the impact of blockchain on improving transparency and traceability within supply chains provides valuable information for practitioners aiming to improve product authenticity and visibility. Implementing blockchain solutions can help companies ensure data integrity and compliance with regulatory standards, thus fostering trust among stakeholders and consumers. This transparency is particularly crucial in industries such as food safety and pharmaceuticals, where traceability is vital for quality assurance and risk management.

Second, the findings on efficiency and cost reduction highlight the potential of blockchain to streamline supply chain operations. By integrating smart contracts and automation, companies can achieve significant cost savings and operational efficiencies. Practitioners can use these insights to redesign business processes, optimize logistics, and reduce redundancies, ultimately enhancing overall supply chain performance. The practical application of blockchain technology in automating transactions and reducing administrative overheads is a game changer for supply chain management.

Third, the study emphasizes the role of blockchain in building resilient and sustainable supply chains. The ability of blockchain to provide real-time data and enhance collaboration among supply chain partners is essential in mitigating risks and recovering from disruptions. Practitioners can use blockchain to develop more robust risk management strategies and ensure continuity in the face of challenges such as natural disasters or global pandemics. In addition, the emphasis on sustainable practices supported by blockchain technology aligns with the growing demand for environmentally and socially responsible supply chains. Companies can adopt blockchain to monitor and report sustainability metrics, ensuring ethical procurement and reducing environmental impact.

Overall, this study informs practitioners about the strategic advantages of integrating blockchain technology into SCM. By adopting blockchain, companies can not only enhance transparency and efficiency, but also build more resilient and sustainable supply chains. The ability of blockchain to trace products from their origin to the end consumer ensures accountability in sustainable practices, allowing companies to verify ethical sources and reduce environmental impact. Furthermore, blockchain facilitates tracking carbon footprints and resource management, contributing to the reduction in waste and energy efficiency within the supply chain. This technology enables companies to meet the growing regulatory demands for sustainability reporting, ensuring compliance with global environmental standards. As a result, blockchain not only enhances operational efficiency, but also supports long-term sustainability goals, making it a key tool to drive both economic and environmental value in supply chain management. These practical implications provide a roadmap for industry leaders to harness the full potential of blockchain and drive innovation in supply chain management.

For academia, this finding underscores the need for research on advanced blockchain architectures, such as layer-two solutions (e.g., sidechains or sharding), that could improve scalability in supply chain contexts. Industry stakeholders can take these insights into account by carefully evaluating blockchain's scalability limitations and investing in adaptive blockchain technologies that can handle increased transaction loads without compromising efficiency. This finding suggests a research gap in the practical applications of privacy-enhancing technologies within blockchain-enabled SCM. Researchers could explore solutions that balance transparency with confidentiality, while industry professionals may consider integrating privacy-preserving technologies in blockchain systems to safeguard proprietary information without sacrificing transparency. This approach is particularly valuable for sectors that manage sensitive data and wish to maintain a competitive edge. Academics can play a crucial role by investigating the feasibility and performance of energy-efficient blockchain protocols within SCM, evaluating their effectiveness relative to traditional consensus models. For industry leaders, adopting energy-efficient blockchain solutions not only aligns with corporate sustainability goals but also positions them as pioneers in responsible technology use. Implementing sustainable blockchain systems may enhance a company's brand image, particularly for customers and stakeholders who prioritize environmental stewardship. Academia can contribute by developing protocols and standards that enable seamless integration between blockchain and other SCM systems, possibly through API-driven approaches or middleware solutions. Industry practitioners, on the other hand, may prioritize investment in interoperable blockchain solutions that align with their existing digital infrastructure. Emphasizing interoperability during implementation planning can reduce disruption and improve the efficiency of blockchain adoption across diverse stakeholders in the supply chain.

5.3. Practical Framework for Implementing Blockchain Solutions in SCM

To support the actionable adoption of blockchain technology within SCM, we propose a five-stage implementation framework designed for scalability, transparency, and sustainability. This framework offers specific guidance for industry practitioners and researchers seeking to design, test, and apply blockchain solutions in diverse supply chain settings.

Stage 1: Planning and Feasibility Assessment

The initial phase involves assessing the feasibility and specific needs for blockchain implementation. Key activities include:

- Determine the primary goals for blockchain adoption, such as enhancing traceability, reducing fraud, or increasing efficiency.
- Not all supply chain challenges require blockchain; therefore, assess whether blockchain is the most suitable solution for addressing identified needs. Evaluate alternative technologies to ensure blockchain is the optimal choice.
- Define KPIs that align with the business objectives, which will later guide the assessment of blockchain's effectiveness in the supply chain.

A feasibility report that outlines objectives, needs, and anticipated benefits, providing a clear justification for adopting blockchain in the supply chain.

Stage 2: Technology Selection and Customization

Once feasibility is confirmed, the next step is to choose the appropriate blockchain platform and customize it to the supply chain's specific requirements.

- Consider adopting energy-efficient consensus mechanisms (e.g., Proof-of-Stake, Proof-of-Authority) for sustainable operations.
- Ensure that the chosen blockchain platform can integrate with existing enterprise resource planning (ERP) systems, using APIs or middleware solutions.
- Select or modify the platform for scalability, particularly if the supply chain involves high transaction volumes.

A customized blockchain solution that aligns with the supply chain's technical, sustainability, and scalability requirements.

Stage 3: Pilot Testing and Prototyping

Before full-scale implementation, pilot testing is crucial to verify the effectiveness and suitability of the blockchain system.

- Develop a pilot blockchain model focused on a specific segment of the supply chain, such as product traceability in one region or among a small group of suppliers.

- Conduct pilot tests that assess transaction speeds, interoperability, and data security. Measure the pilot's outcomes against the established KPIs.
- Gather insights from key stakeholders involved in the pilot to identify operational challenges and make necessary adjustments.

A validated prototype that demonstrates blockchain's functionality within the supply chain and identifies adjustments needed before broader implementation.

Stage 4: Full-Scale Implementation and Integration

After successful pilot testing, the blockchain solution can be scaled across the entire supply chain.

- Implement blockchain in phases, gradually extending to additional segments of the supply chain to manage risk.
- Ensure all stakeholders, from suppliers to logistics providers, are trained on the blockchain system to optimize usability and minimize operational disruptions.
- Continuously monitor blockchain operations, troubleshooting any issues related to data integrity, transaction speed, or system interoperability.

A fully operational blockchain-enabled supply chain, with comprehensive stakeholder engagement and minimized integration risks.

Stage 5: Evaluation and Continuous Improvement

Once blockchain is integrated, ongoing evaluation is essential to maximize long-term benefits and address emerging challenges.

- Regularly review blockchain performance relative to the KPIs set during the planning stage, such as cost savings, transparency improvements, or enhanced traceability.
- As blockchain and supply chain technologies evolve, adapt the system by integrating new features (e.g., privacy-preserving mechanisms and scalability solutions).
- Document insights gained from blockchain implementation to provide valuable data for future supply chain innovations. Share findings with stakeholders and researchers to contribute to broader industry knowledge.

A sustainable, scalable blockchain system that is continuously optimized to meet evolving supply chain needs.

6. Conclusions

Our research offers a unique contribution to the growing field of blockchain technology integration in supply chain management (SCM) by utilizing an extensive bibliometric analysis. Departing from the typical exploratory approaches seen in previous studies, our method delivers a more thorough examination, spotlighting influential publications, key contributors, and emerging trends within the sector. This approach has allowed us to identify significant gaps in the research and provide clear pathways for future exploration. By delivering a comprehensive overview of blockchain-SCM literature, this study aims to equip both academics and industry experts with valuable insights and a solid framework for understanding the evolving landscape of the field.

Our co-word analysis demonstrates the critical roles of transparency, efficiency, and resilience in supply chain management, reflecting our methodological rigor. Cluster 1 elucidates the intricacies of blockchain's influence on improving transparency and traceability in supply chains. Subsequently, Clusters 2 and 3 explore the potential for efficiency and cost reduction, as well as the importance of building resilient and sustainable supply chains. Our keyword co-occurrence analysis enhances the debate by emphasizing important academic discussions and interconnections among frequently utilized keywords. These discussions encompass a wide range of topics, from the influence of smart contracts on supply chain automation to the potential of blockchain-facilitated sustainable practices.

Despite its significant achievements, the study has limitations. In this analysis, we only used papers indexed in the Scopus database. Alternative databases, such as Web of Science and Google Scholar, may produce differing results, featuring a larger volume of indexed papers [39]. Despite this limitation, there is a common assertion that the exclusive use of the Scopus database has limited the number of papers indexed in prestigious journals, potentially compromising their quality [40]. We may also reference other academic sources [41–43] to bolster the study's conclusions.

The text mining techniques used in this study, including latent Dirichlet allocation (LDA) for topic modeling and co-word analysis, come with inherent limitations that may impact the accuracy of theme identification. Specifically, text mining relies on the frequency of word co-occurrences to identify themes, which can lead to challenges in capturing nuanced, context-dependent meanings of words. For example, certain terms like 'efficiency' or 'security' can have different implications depending on industry or context, but text mining may not always accurately differentiate these meanings.

Additionally, LDA assumes that each document can be represented by a mixture of topics, which may not always align with the complex, multidimensional nature of some research articles. As a result, there is a risk of oversimplifying themes or missing subtle emerging trends that are not yet strongly represented in the literature.

The articles analyzed in this study span a specific time frame, from 2010 to 2020. Given the rapid pace of technological advancements in both blockchain and SCM, there is a risk that some of the findings may already be outdated, particularly as new blockchain applications and innovations emerge. For example, developments in blockchain scalability solutions (e.g., layer-two protocols), privacy-preserving technologies, and blockchain's role in emerging fields such as quantum computing may not be fully captured in this dataset.

6.1. Limitations

This study focused on articles indexed in the Scopus database, which may introduce limitations related to the geographical and industry scope of the analyzed articles. Although Scopus is a comprehensive academic database, it may not fully represent research from regions where English-language publications are less common, such as Asia, Africa, or Latin America. As a result, SCM blockchain applications that are specific to certain regions or industries might be underrepresented in this analysis.

Similarly, the majority of the literature analyzed pertains to well-researched industries such as logistics and manufacturing, while other sectors (e.g., healthcare and agriculture) may not have been as thoroughly covered. The implications of blockchain technology for these underrepresented industries could differ, and, thus, the findings of this study may not fully capture the diversity of blockchain applications in various sectors.

Although the text mining approach used in this study aimed to provide an objective data-driven analysis of the themes in the literature, there is still potential for researcher bias in the interpretation of these themes. For example, a manual review of the topics identified by the LDA model required subjective decisions about the relevance and importance of certain themes. This introduces the risk that certain themes may have been over-emphasized or underrepresented based on the researchers' interpretations.

This study provides a comprehensive overview of the existing literature on blockchain integration into supply chain management (SCM) through bibliometric analysis and text mining. However, several gaps in the literature emerged, suggesting areas for future research. The following specific research questions and hypotheses are proposed to address these gaps. Although the potential of blockchain to improve transparency and efficiency is widely acknowledged, concerns about scalability, particularly in global supply chains, remain underexplored. Future studies should investigate how scalable solutions such as layer two technologies can be adapted to specific needs and industries in the supply chain, as well as the potential limitations of these approaches.

The analysis revealed that regulatory and legal challenges are underexplored despite their critical role in the adoption of blockchain technology. Future research should focus on comparative legal studies across different regions, identifying how blockchain can comply with local regulations while promoting global supply chain integration. Additionally, more research is needed on the enforceability of smart contracts in different legal jurisdictions.

The interoperability between different blockchain platforms and legacy systems has emerged as a critical challenge that has not been adequately addressed in the current literature. Future studies should explore the development of protocols and middleware solutions that allow for interoperability between different blockchain platforms and legacy systems. This could involve collaborations between technology providers, industry groups, and standard-setting bodies.

6.2. Future Research

The tension between transparency and data privacy is a critical issue that has not been adequately explored in the literature, particularly in industries that handle sensitive information. Future research should examine the feasibility and effectiveness of privacy-enhancing technologies within blockchain networks, particularly in industries where confidential information (e.g., customer data and financial details) is involved.

Although blockchain's contribution to sustainability in supply chains is increasingly recognized, the specific mechanisms by which blockchain supports sustainability initiatives are not well understood. Future studies should focus on specific use cases where blockchain is applied to sustainability initiatives, such as tracking carbon footprints, reducing material waste, or promoting fair trade practices. These studies could provide empirical evidence on blockchain's environmental and social impacts. Blockchain has the potential to reshape power dynamics and decision making in supply chains, raising important ethical and social questions that have not yet been fully explored. Future research should investigate these ethical dilemmas, focusing on how the blockchain alters power relationships, especially for smaller or marginalized stakeholders in global supply chains. Additionally, more research is needed on how organizations can ethically manage the balance between transparency and surveillance.

Blockchain technology has significant potential to advance supply chain management (SCM), but its full impact can only be realized through interdisciplinary research that integrates insights from other fields. By combining blockchain with domains such as sustainability, cybersecurity, artificial intelligence (AI), and data science, future studies can address complex, multifaceted challenges and create more holistic solutions. The ability of blockchain to track and verify the origins of products, ensure ethical sources, and reduce inefficiencies is closely aligned with the sustainability goals. However, the intersection of blockchain and sustainability in supply chains remains underexplored, particularly with respect to environmental impacts and social equity. This question requires collaboration between blockchain technologists, environmental scientists, and supply chain experts. Research should focus on developing blockchain systems that track sustainability metrics such as carbon footprints, water usage, and waste management. In addition, interdisciplinary studies could examine the social implications of blockchain, such as its role in promoting fair trade practices and supporting workers' rights in global supply chains.

Blockchain, SCM, and Cybersecurity

Supply chains are increasingly vulnerable to cyberattacks due to the proliferation of digital technologies and interconnected systems. The inherent security features of the blockchain, such as encryption and immutability, make it a promising solution for securing supply chain data. However, the intersection of blockchain and cybersecurity in supply chains has not been extensively explored.

The interdisciplinary research focuses on this question and invites collaboration between blockchain developers, cybersecurity experts, and supply chain managers. Future research could focus on developing blockchain-based cybersecurity frameworks that protect against data breaches, fraud, and cyberattacks in supply chains. Topics such as the use of blockchains to secure Internet of Things (IoT) devices, which are increasingly used in smart supply chains, should also be explored.

Blockchain, SCM, and Artificial Intelligence (AI).

The combination of blockchain and AI offers opportunities to create smarter and more automated supply chains. AI can optimize processes such as demand forecasting, inventory management, and logistics, while blockchain can ensure data integrity and transparency across these operations. Interdisciplinary studies between blockchain technologists, AI researchers, and supply chain professionals could focus on creating intelligent blockchain platforms. These platforms could utilize AI algorithms for predictive analytics while taking advantage of the security and transparency features of the blockchain. Research could also explore how AI-powered smart contracts can autonomously manage supply chain transactions, reducing delays and human errors.

Blockchain, SCM, and Ethics

As blockchain introduces unprecedented levels of transparency and traceability into supply chains, ethical questions arise about data privacy, surveillance, and fair treatment of all stakeholders. Cross-disciplinary research between ethicists, legal experts, and supply chain managers can help address these concerns. Research in this area should focus on balancing transparency with data privacy and ensuring that blockchain is used in a way that promotes ethical decision making without infringing on privacy rights. Furthermore, studies could explore how blockchain can be used to promote social justice and prevent the exploitation of vulnerable populations in global supply chains.

As blockchain technology continues to evolve, several emerging trends and technologies are poised to significantly influence its integration into supply chain management (SCM). These technologies, such as artificial intelligence (AI), quantum computing, and the Internet of Things (IoT), offer exciting new possibilities to improve the efficiency, security, and transparency of supply chains. This section discusses how these emerging technologies could shape future research directions in blockchain and SCM. The integration of artificial intelligence (AI) with blockchain is one of the most promising trends for the future of SCM. AI can enhance blockchain systems by enabling predictive analytics, process optimization, and automated decision making.

The ability of AI to analyze large volumes of data in real time can complement the secure and transparent data infrastructure of the blockchain. For example, AI algorithms could be used to predict demand, optimize inventory levels, and manage logistics, while blockchain ensures that all transactions and data exchanges are secure and tamper-proof. Additionally, AI-powered smart contracts could autonomously manage supply chain agreements, reducing delays and errors. Future research should focus on developing AI-driven blockchain platforms that can automate supply chain processes while maintaining the security and transparency benefits of blockchain. Exploring how AI and blockchain can work together in specific industries, such as manufacturing or logistics, will be crucial to understanding the full potential of this integration.

Quantum computing is an emerging technology that has the potential to disrupt both blockchain and SCM. Although quantum computing can solve complex problems faster than classical computers, it also poses a threat to the cryptographic security of the blockchain. Quantum computers could potentially break the encryption algorithms on which the blockchain relies for security, raising concerns about the future of blockchain-based supply chains. However, quantum computing could also be used to optimize supply chain processes by solving optimization problems much faster than traditional computers.

Future research should explore how blockchain technology can be adapted to withstand quantum computing threats through the development of quantum-resistant cryptographic algorithms. At the same time, researchers should investigate how quantum computing can be used to improve supply chain optimization, particularly in areas such as logistics, inventory management, and resource allocation. The integration of devices from the Internet of Things (IoT) with blockchain is another emerging trend that is transforming supply chain management. IoT devices can provide real-time data on the location, condition, and movement of goods, while the blockchain ensures the security and transparency of these data.

The combination of IoT and blockchain can create fully transparent supply chains where every step, from production to delivery, is monitored and recorded in real time. This has significant implications for improving traceability, reducing fraud, and ensuring the quality of goods, especially in industries such as food and pharmaceuticals. Future research should focus on developing blockchain-based IoT solutions that can be deployed on a scale across different industries. Researchers should also investigate how data collected by IoT devices can be securely integrated into blockchain networks to ensure that the entire supply chain is transparent and accountable.

Decentralized autonomous organizations (DAOs) represent an emerging trend in blockchain that could revolutionize supply chain management by enabling fully decentralized and automated decision-making processes. DAOs are organizations that are governed by smart contracts on a blockchain, allowing for decentralized and automated decision making without the need for centralized management. In supply chain management, DAOs could be used to manage logistics, procurement, and supplier relationships autonomously, reducing administrative overhead and improving efficiency. Future research should explore the feasibility of implementing DAOs in supply chains, focusing on the potential benefits of decentralization as well as the challenges related to governance and accountability. Studies could also investigate how DAOs interact with existing legal and regulatory frameworks.

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