The impact of blockchain technology on supply chain efficiency: A review

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Abstract. As intricate global trade demands new solutions, traditional supply chains struggle with opacity, traceability, and security concerns. In response to the present apprehensions, Blockchain technology (BT) offers an appealing solution through its decentralised and transparent ledger. This paper critically examines the transformative impact of BT on supply chain efficiency, exploring its potential to revolutionise traditional, often opaque, and error-prone systems. This study utilises a systematic literature review of 75 selected papers to provide insights into how blockchain technology is integrated into supply chain management, showcasing its potential. The paper aims to provide a balanced and nuanced perspective on the impact of blockchain technology on supply chain efficiency. It highlights the transformative potential of this technology while emphasising the need for careful consideration of its challenges and limitations before wide-scale adoption.

Keywords: Blockchain technology; Supply chain efficiency**;** Supply chain management

1 Introduction

Digitalisation, a transformative influence in the 21st century, is globally influencing every aspect of life. It powers new business models, pushes product and service modernization, and infuses a new manufacturing revolution. This technological flow allows businesses to react agilely to demand shifts, optimise product quality, and reshape the factory operations and supply chains through digital processes, impacting resource consumption and overall competence.

The German government presented an "Industry 4.0" initiative to exemplify the impact of digital technologies on industrial production (Glas & Kleemann, 2016). Launched in 2011 during the Hannover Fair in Germany (Frederico et al., 2020), Industry 4.0, also termed the Fourth Industrial Revolution (or 4IR), involves amalgamate systems through digitalisation among devices using the Internet of Things (IoT) and Cyber-Physical Systems (CPS) (Abdirad & Krishnan, 2020). Industry 4.0 is distinguished by the advanced digitalisation and assimilation of industrial manufacturing and logistics processes, incorporating the internet

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and "smart" objects (products and machines). It also involves the blending of the real and virtual worlds through Information and Communications Technology (ICT). The rise of Industry 4.0 paradigms emphasises the necessity for production systems to transition towards "smart" production (Wamba & Queiroz, 2022) and "smart" supply chains. A "smart" supply chain is defined as a modern and interconnected system that transcends isolated, regional, and single-firm applications, enabling comprehensive and systematic implementation across the entire supply chain ecosystem (Abdel-basset et al., 2018). Within the context of Industry 4.0, a resilient and self-sustaining intelligent supply chain can operate efficiently, even in an environment marked by dynamic changes (refer to Figure 1).

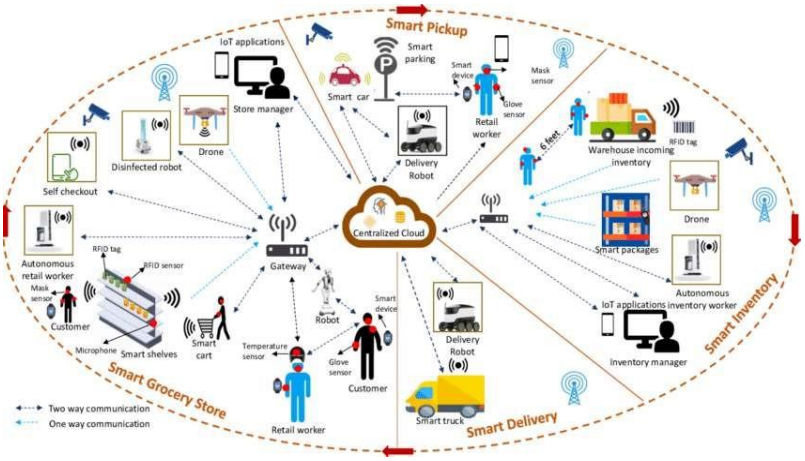

Fig. 1. Smart and Connected Supply Chain Management Scenario (Source: Gupta et al., 2021)

Despite the advantages offered by these services, significant privacy concerns may arise due to the fact that connected devices (the things) disseminate sensitive personal data and disclose the behaviours and preferences of their owners (Reyna et al., 2018). Privacy invasion and risk become prominent, especially when a centralised system governs the data. The lack of transparency in supply chain information diminishes trust between parties and impedes authentic information exchange (Lim et al., 2021). Blockchain, one of the most recent disruptive technologies, has evolved to address these threats. Proposed in 2008 and implemented in 2009 (Zheng et al., 2018), blockchain operates as a peer-to-peer network accessible to everyone without requiring users to provide personal details for authorisation (Ali Syed et al., 2019). Since its foundation and the initiation of 'Bitcoin' in 2008 by Nakamoto, this decentralised and trustless peer-to-peer (P2P) technology has arisen as a major transformative force in business and is predicted to see widespread adoption across various industry and service sectors (Pournader et al., 2019).

Despite the extensive applications of blockchain and its potential to inflame changes in various types of supply chains, especially in terms of new functioning models, the literature on Blockchain technology in the field of Supply Chain Management (SCM) is still in its early stages (Queiroz & Fosso, 2019).

Therefore, this paper makes contributions in three research domains: the central concept of blockchain technology, supply chain management (SCM), and the agricultural and food supply chain. The research offers abundant resources to study each of these three topics. The paper begins by introducing blockchain technology. Subsequently, it explores blockchain technology's significance in Supply Chain Management and agri-food supply chain management.

2 Review Methodology

A systematic literature review was conducted to investigate the use of blockchain technology in supply chains. Following the PRISMA guidelines, relevant publications were identified through keyword searches across databases like PubMed, Scopus, Google Scholar, and Web of Science. The components of the literature review are outlined in Table 1.

Table 1: Literature review components

Databases	**PubMed, Scopus, Google Scholar, and Web of Science**
Keywords	Distributed Ledger Technology (DLT), Blockchain Technology, Industry 4.0, Supply Chain Management, Agri-Food Supply Chain, Food Security, Traceability, Tracking, Internet Of Things, Digital Supply Chain, Logistics, Transparency, Sustainability
Publisher	Elsevier, Emerald, MDPI, Wiley, Taylor & Francis, Springer, IEEE, Inderscience, Sage
Document Type	Journals, Conference Paper, Government Reports, Magazine
Date Range	From 2013 to 2023
Language	English
Initial Search	320 documents
Final Selection	75

This review delved into research published from 2013 till today to incorporate the most recent advancements in the field. From an initial pool of 320 papers identified through targeted keyword searches, a rigorous selection process guided by PRISMA principles yielded a concise set of 75 research papers for detailed analysis. Figure 2 illustrates the statistics of the 75 selected research articles published from 2013 to 2023. The figure also demonstrates a significant increase in researchers' interest from 2019 onwards, steadily rising after that. Prior to 2018, research was limited due to the early stages of blockchain technology. Figure 3 offers a detailed examination of the publisher sources, indicating that multiple databases were consulted, including MDPI, Elsevier, Wiley, Taylor & Francis, Inderscience, Emerald, IEEE, Springer and Sage. The majority of the publications are from Elsevier and Emerald.

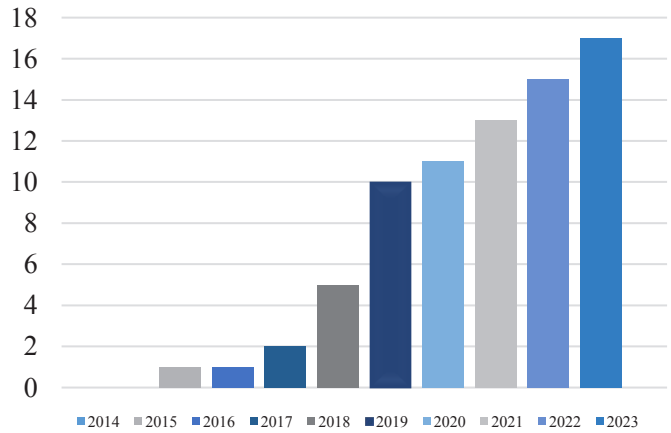

Fig. 2. Year-wise analysis

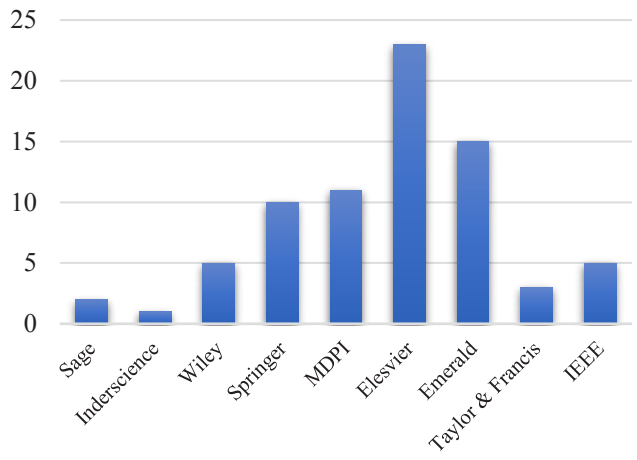

Fig. 3. Publisher-wise analysis

Figure 4 illustrates the journal names of the selected 75 articles. However, this graph displays only the top journals among the 75 research articles.

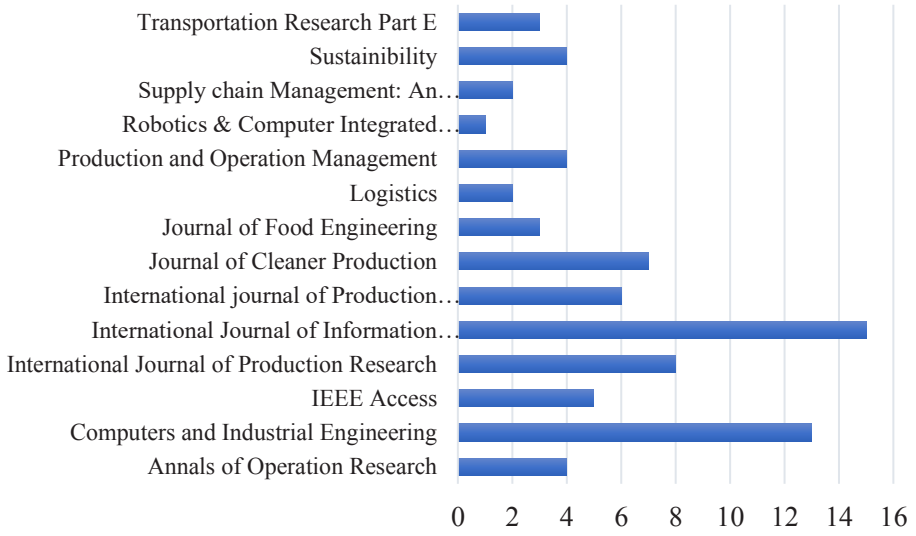

Fig. 4. Top Journal wise analysis

Figure 5 reveals the characteristics of the chosen articles, classified as conceptual, review, empirical, framework, algorithm, or mathematical. Remarkably, reviews and conceptual studies are predominant, constituting 37% of the total, focusing on the fundamentals of BT and its integration into the supply chain, while 28% provide comprehensive research analyses. In contrast, only 12% present empirical findings, and 9% propose models for blockchain-based supply chains, indicating a potential for additional research in these domains.

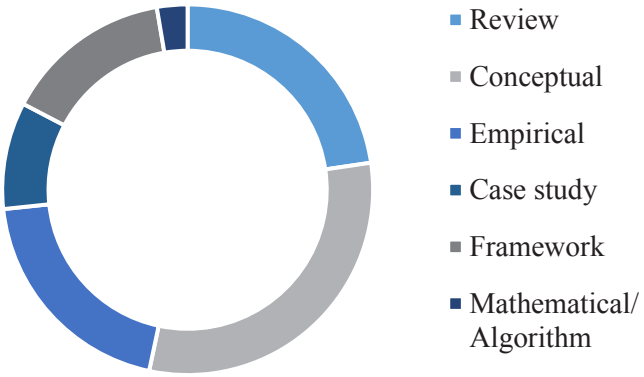

Fig. 5. Approach-wise analysis

3 Literature Review

Blockchain creates a tamper-proof, distributed ledger chain by adding cryptographic signatures to individual data blocks (Maesa & Mori, 2020). This technology holds promise for tackling the challenges of complex supply chains, where agility, speed, and transparency are crucial (Cole et al., 2019). From real-time communication and trust-building to faster payments, lower costs, and improved sustainability, blockchain offers a diverse range of benefits for supply chain management (Bai & Sarkis, 2020). Its inherent security, transparency, traceability, and efficiency make it a compelling option for integrating into modern supply chain operations (Wamba & Queiroz, 2022). Various applications and implementations of Blockchain technology are evident in different industries and sectors, including but not limited to the logistics industry, supply chain industry, banking industry, health industry, construction industry, agriculture industry, and more (Figure 6).

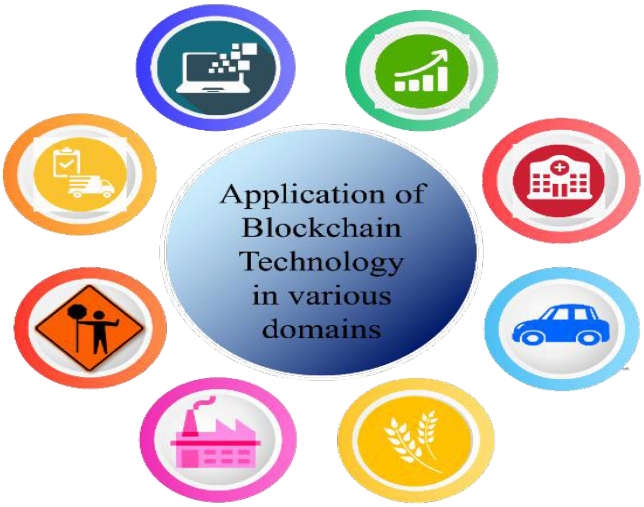

Fig. 6. Various application domains of Blockchain Technology

The acceptance of BT is swiftly progressing in the evolving industries. Although it is still in the budding stages of technological maturity and innovative experimental adoption, it is vital to understand its fundamental concepts before initiating this study.

Blockchain Technology (BT) had made an appearance as one of the most significant technological innovations in recent years. It functions as a decentralised and distributed database of transaction records, which is validated and maintained by a global network of computers (Sarmah, 2018). BT is a peer-to-peer transaction platform that abolishes the requisite of the third-party intermediaries (Kamble et al., 2019). It consists of a chain of interconnected blocks cholding timestamped transactions secured through public-key cryptography and endorsed by network participants (Tijan et al., 2019). Figure 7 (a & b) provides an overview of BT's workflow and illustrates the structure of each block.

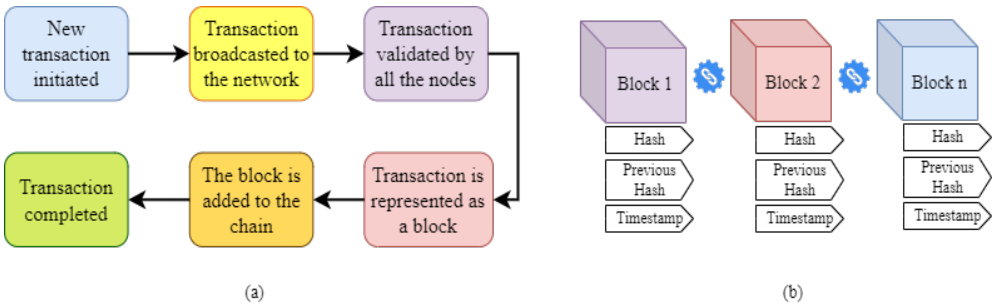

Fig. 7. (a) Blockchain Technology workflow (b) Structure of each block

The workflow of BT, showed in the figure, begins with transaction initiation. Consequently, this transaction propagates through a decentralised network of computers called nodes for authentication. Upon consensus among the nodes, the validated transaction is assembled into a block and appended to the existing blockchain, a tamper-proof, chronological ledger of transaction blocks.

The main goal of this study is to explore the impact of adopting Blockchain technology on supply chain performance. So, a comprehensive literature review was undertaken. This review aimed to comprehend the fundamental concepts of Blockchain technology, examine its applications in supply chains, identify barriers to adoption, explore the diverse performance indicators associated with blockchain-enabled supply chains, and pinpoint potential research gaps within this domain.

This literature review is organised into three categories.

1) Basic concept of Blockchain Technology.

2) Blockchain integration in Supply Chain Management.

3) Blockchain integration in Food Supply Chain Management

- **Basic concept of Blockchain Technology**

The momentum for adopting blockchain is surging as the industry undergoes rapid evolution. However, it is still in the early stages of technological maturity and innovative experimental adoption. Therefore, it is crucial to grasp the fundamental concepts of blockchain before embarking on this research project. Table 2 presents noteworthy works elucidating the fundamental concepts of Blockchain Technology.

Table 2: Some of the notable works on understanding the basic concept of Blockchain Technology

Author	Title	Findings
Zheng et al. (2018)	"Blockchain challenges and opportunities: a survey"	A thorough examination of Blockchain Technology has been conducted, and future research directions have been identified.
Casino et al. (2019)	"A systematic literature review of blockchain-based applications: current status, classification and open issues"	This paper provided an extensive literature review of applications based on blockchain across various fields and identified potential future research areas. It holds value for both academics and practitioners.
Ali Syed et al. (2019)	"A Comparative Analysis of Blockchain Architecture and its Applications: Problems and Recommendations"	This research study presented a comprehensive overview of the entire Blockchain ecosystem. Further, different Blockchain consensus models, platforms, and their implementations were analysed.
Maesa & Mori, (2020)	"Blockchain 3.0 applications survey"	This paper examined six innovative situations: "end-to-end verifiable electronic voting", "healthcare records management", "identity management systems", "access control systems", "decentralisation notary", and "supply chain management".
Zheng & Lu (2022)	"Blockchain technology: recent research and future trend"	A systematic review was carried out on the implementation of Blockchain in information systems during 2016 to 2020.

- **Blockchain Integration in Supply Chain Management**

Blockchain technology's inherent decentralisation and immutability hold immense promise for supply chain optimisation. Moving beyond traditional models that prioritise inventory reduction, blockchain addresses key challenges like transaction and inventory cost minimisation, bottleneck elimination, and resilience to economic downturns and material shortages. Furthermore, its secure and transparent traceability capabilities empower trust-building and ethical sourcing practices. Given these multifaceted benefits, blockchain emerges as a compelling choice for industries and financial partners seeking to revolutionise their supply chain management. Table 3 delves into noteworthy works that elaborate on the integration of blockchain in the supply chain.

Table 3. Some of the notable works on blockchain integration in supply chain management

Author	Title	Findings
Queiroz et al. (2020)	"Blockchain and supply chain management integration: a systematic review of the literature"	It was found that the purpose of this paper was to locate, evaluate, and organise the literature on blockchains, as well as to shed light on their current applications in supply chain management.

Frizzo-Barker et al. (2020)	"Blockchain as a disruptive technology for business: a systematic review"	It was discovered that a PRISMA-guided systematic review of Blockchain research in the business literature from 2014 to 2018 was conducted.
Meidute-Kavaliauskiene et al., (2021)	"An integrated impact of blockchain on supply chain applications"	This paper discussed the impact of applying Blockchain technology on the supply chain to examine its transparency & flexibility, and supplier trust.
Pournader et al. (2019)	"Blockchain applications in supply chains, transport, and logistics: a systematic review of the literature"	A systematic literature review was conducted on Blockchain applications in supply chain management, logistics management, and transport management, from industrial and academic frontiers to provide themes for further study on this topic.
Azzi et al. (2019)	"The power of a Blockchain-based supply chain"	In order to develop a trustworthy, transparent, authentic, and secure system, the integration of Blockchain technology into the supply chain architecture was described. Additionally, it combined theoretical and practical applications to create an effective Blockchain-based supply chain.
Dietrich et al. (2021)	"Review and analysis of Blockchain projects in supply chain management"	Increasing supply chain transparency is found to be the primary aim of current Blockchain practices in supply chain management.
Yavaprabhas et al. (2023)	"Blockchain as the trust-building machine for supply chain management"	This paper delves into the trust-building potential of blockchain in supply chains, introducing "blockchain entrusted models" to illustrate the three-step trust development process.
Maria et al. (2023)	"How blockchain technology improves sustainable supply chain processes: a practical guide"	This study comprehensively analyses blockchain's applications and benefits in supply chain management, culminating in a theoretical framework for optimising performance through blockchain integration.
Gonczol et al. (2020)	"Blockchain Implementations and Use Cases for Supply Chains–A Survey"	The applicability of blockchain in the supply chain was explored from the previous works of researchers and practitioners to find future projects focusing on enhancing the technology and its applications.
(Khan et al., 2022)	"Blockchain technologies as enablers of supply chain mapping for sustainable supply chains"	The current study investigates the effectiveness of blockchain technologies in facilitating the mapping of the supply chain and their integration. Additionally, the impact of blockchain technologies on the sustainability of the supply chain is assessed.

- **Blockchain Application in Food Supply Chain Management**

Our global food system, plagued by biodiversity loss, waste, and food insecurity, faces a critical crisis. The COVID-19 disruptions necessitated continuous evolution towards resilient, agile business models. This quest for transparency and efficiency converges with the emergence of digitalisation in food supply chains. However, traditional technology often proves resource-intensive. This section delves into the promising integration of blockchain technology, a distributed ledger system enabling unprecedented traceability, safety, and sustainability within the food supply chain ecosystem.

Table 4. Some of the notable works on blockchain integration in Food Supply Chain Management

Author	Title	Findings
Zkik et al. (2022)	"Exploration of barriers and enablers of Blockchain adoption for sustainable performance: implications for e-enabled agriculture supply chains"	This study uncovers the roadblocks and facilitators for integrating blockchain technology (BT) into sustainable supply chain practices (SSCP) within e-agriculture. The findings guide managers to reallocate resources and prioritise key enablers for successful BT implementation.
Panchal & Gedam, (2021)	"Antecedents for Blockchain technology-enabled sustainable agriculture supply chain"	In this study, structural equation modelling (SEM) was formulated by the survey of respondents from Indian ASC industries to measure the performance of Blockchain-enabled sustainable supply chains.
Agi & Kumar (2022)	"Blockchain technology in the supply chain: An integrated theoretical perspective of organisational adoption"	In this article, an integrated framework for Blockchain adoption in the supply chain was developed by identifying and evaluating the enablers and their interdependencies.
Saurabh & Dey, (2021)	"Blockchain technology adoption, architecture, and sustainable agri-food supply chains"	This paper identified the potential drivers for implementing Blockchain technology in the grape wine supply chain.
Sharma et al. (2022)	"Blockchain Technology Adoption: Multinational Analysis of the Agriculture Supply Chain"	This paper investigated the application of Blockchain technology in the agriculture supply chain, concentrating on assessing the trends in developed vs. developing economies.

4 Discussions & Findings

Technology has revolutionized industries, transforming supply chains into agile, collaborative networks. Blockchain emerges as the next game-changer, promising to reshape trust and transparency – the lifeblood of efficient supply chains. This framework tackles challenges step-by-step, paving the way for a seamlessly integrated, blockchain-powered future, boosting transparency and efficiency.

An inclusive analysis of available literature suggests that blockchain research in the operations and supply chain management is a flourishing field, focused on theoretical prospects and trends. As Ding et al. (2019) emphasized, limited research exists on concrete implementation modelling. Existing studies, including Tijan et al. (2019) and Park & Li (2021), identify integration challenges but provide minimal practical guidance. This study steps into this key void, focusing on blockchain adoption challenges and empirical validation in real-world supply chain scenarios.

From this viewpoint, the following findings are discussed below.

1) **Absence of an effective Blockchain-enabled supply chain framework.** While a very few papers touch on blockchain implementation in supply chains (Casado-Vara et al., 2018), existing frameworks highlight transparency and traceability (Venkatesh et al., 2020). However blockchain offers far more! This study offers a comprehensive framework leveraging blockchain's full potential, immutability, privacy, risk management, and empower businesses and lower supply chain losses.

2) **No focus on sustainability.** Food waste, a manifold sustainability challenge, demands exigent attention. Existing research on blockchain's role in this domain is largely inceptive (Esmaeilian et al., 2020) and often hidden within individual supply chain segments. This study addresses this gap by proposing a comprehensive framework leveraging blockchain's potential to enhance food quality, safety, and sustainability across the entire supply chain.

3) **Inadequate empirical validation.** Blockchain's potential to revolutionize supply chains is widely recognized, but its materialization is baffled. Existing research, though plentiful, is often theoretical and oversees technical complexities and integration challenges (Madumidha et al., 2019).

4) **No focus on the industries of developing countries.** BCT's global impact on supply chains is undeniable, but its reach is uneven. Developed economies dominate the research landscape (Salah et al., 2019; Hasan et al., 2020; Ding et al., 2019), leaving a critical gap in understanding its potential for developing economies.

5) **Lack of effective decision-aid model for evaluating the impact of Blockchain technology in the supply chain.** Existing frameworks for blockchain in supply chains lack a vital component in anticipating and mitigating implementation challenges.

5 Conclusion

Despite severe competition, supply chain opaqueness remains a major obstacle for businesses. While companies struggle for cost reduction and competence, blind spots in second and third-tier suppliers create barriers. Customers, especially in food and luxury markets, demand transparency and are willing to pay for it. With its secure and transparent data, blockchain technology emerges as a powerful solution, illuminating every stage of the supply chain and empowering businesses to make informed decisions.

This review aspires to be the initial comprehensive study that systematically integrates and consolidates previous research on blockchain and trust, addressing the pivotal question of how this technology can transform the trust element within supply chains. This review concludes that, despite the evident beneficial features of blockchain technology, further research is essential to address several key shortcomings. These include the absence of well-defined implementation frameworks, inadequate consideration of sustainability in the context of blockchain adoption, insufficient empirical validation of theoretical benefits, and limited

emphasis on implementing this technology in developing or underdeveloped countries.

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