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Barriers to Blockchain Adoption in Circular Supply Chain Management: A Systematic Review and TISM-MICMAC Analysis

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Abstract. This study examines the practical challenges organizations encounter in adopting blockchain for circular supply chain management. The objective is to provide actionable insights for managers and policymakers to facilitate blockchain adoption for strengthening circularity within supply chains and enhancing circular supply chain performance. A comprehensive systematic literature review is conducted with 34 articles to identify key barriers. Subsequently, the key barriers were modeled using inputs from nine experts through Total Interpretive Structural Modelling (TISM) and MICMAC analysis. The results indicate that barriers such as lack of government regulations and lack of stakeholder involvement function as root-level drivers, while mid-level feedback barriers include cost, lack of trust, and lack of standardization. At the upper level, outcome barriers such as security, privacy, and scalability emerge as dependent effects. The findings highlight that successful blockchain adoption in circular supply chains requires first strengthening institutional and collaborative foundations, followed by addressing technical limitations. Overall, the study emphasizes real-world implementation considerations and the adoption of circular economy principles within blockchain-enabled supply chain transformation.

Keywords: Blockchain, Circular Supply Chain Management, TISM, MICMAC

1. Introduction

Due to changes in consumption behavior and the swelling demand for items, we are witnessing an increased demand for natural resources, including water, land, raw materials, and energy, creating pressure on the environment (Franklin-Johnson et al., 2016). Over the past 150 years, linear economy models have dominated the industrial revolution (MacArthur, 2015). These models are based on manufacturing products, selling them, and ultimately disposing of waste (Govindan & Hasanagic, 2018). Ghisellini et al. (2016) have defined this model as the "take-make-use-destroy" model. The impact on society and the conservation of scarce resources is not considered in linear models (Kok et al., 2013). Therefore, the concept of circular economy (CE) was introduced. The advantages of the CE systems are discussed in the literature with a wide range of applications in manufacturing (Roy et al., 2022), service (Tukker, 2015), supply chain (Zhu et al., 2022), construction (Smol et al., 2015), among others. Earlier studies have focussed on CE in general (Pan et al., 2015; Ghisellini et al., 2016). Many researchers have argued that organizational performance is directly affected by the effectiveness of the supply chain management (Xia & Ruan, 2020; Ozkan-Ozen et al., 2020).

Circular Supply Chain Management (CSCM) is a "*strategic framework*" that extends conventional supply chain management techniques to conform with the tenets of CE (Garcia-Buendia et al., 2024). Organizations should identify and eradicate key barriers so that the implementation of CE from a supply chain perspective can be effectively achieved. Blockchain is understood as a "digital data structure, a shared and distributed database that contains a continuously expanding log of transactions and their chronological order" (Andoni et al., 2019, p. 145). Blockchain may enhance CSCM by accelerating resource utilization, minimizing waste, and improving the robustness and adaptability of circular supply networks (Rane et al., 2025). Blockchain can monitor and evaluate the product life cycle, enabling all CSCM stakeholders to enhance resource efficiency and bolster supply resilience (Farooque et al., 2019a). In the context of supply chain management, BLOCKCHAIN technology has been proven to enhance the guarantee of human rights and equitable labor practices (Saberi et al., 2019).

Studies on barriers to developing circular supply chains have lately gained increasingly scholarly attention. A limited number of studies have examined to understand these barriers in industries like dairy (Kazancoglu et al., 2021), agriculture (Sharma et al., 2025), construction (Scipioni et al., 2021), apparel (Rashid et al., 2024), textile (Kazancoglu et al., 2020), food (Farooque et al., 2019b), and plastic (Maione et al., 2022). Scholars suggest that blockchain technologies have the potential to enhance CSCM by improving traceability and information sharing, reducing operational inefficiencies and coordination costs, strengthening data security and privacy, and supporting sustainability objectives through greater transparency and resource optimization (Upadhyay et al., 2021). Consequently, understanding the barriers that hinder the implementation of blockchain in CSCM has become a critical research and managerial priority.

Despite its potential benefits, several barriers impede the full realization and optimization of blockchain's potential in CSCM. To maximize the outcomes of blockchain adoption in CSCM, it is essential to manage these barriers through strategic interventions. With this consideration, this paper aims to identify the main barriers to implementing blockchain technology in CSCM through a systematic literature review. After identifying the major barriers, TISM modelling was conducted to examine the interrelationships among the identified barriers.

Although prior studies have examined blockchain adoption barriers in supply chain, the existing literature exhibits three notable gaps. First, most studies have focused on blockchain adoption in general supply chain contexts, with limited attention to CSCM. Second, previous investigations have primarily employed methods such as ISM, DEMATEL, fuzzy-MCDM, and bibliometric analyses, which mainly identify, rank, or classify barriers but provide limited insights into their hierarchical interdependencies and causal mechanisms. Third, no comprehensive study has integrated a systematic literature review to

identify barriers with a total interpretive structural modelling (TISM) approach to explain how different barriers interact and collectively influence blockchain adoption in CSCM.

This paper is organized into eight sections. Following the introduction (Section 1), Section 2 presents the systematic literature review and methodological design for barriers in CSCM using the PRISMA approach. Section 3 contains the methodological design of the study and the TISM approach is presented in Section 4. The discussion and conclusions of this study are presented in section 5 and section 6, respectively. Lastly, implications and limitations with future research directions are discussed in section 7 and section 8 respectively.

2. Systematic Literature Review

Scholars have argued that systematic reviews play an instrumental role in (1) developing "*new knowledge*" (Kunisch et al., 2023a) and (2) advancing existing knowledge (Kunisch et al., 2023b) for both industry and academia. In contrast with narrative or critical reviews, which usually do not follow a systematic procedure for synthesizing existing research, a systematic review is guided by a stringent review protocol that demarcates the steps, criteria and indicators (Kumar et al., 2022a), thereby ensuring generativity, rigor, transparency, and replicability (Fan et al., 2022). The current study adopts a PRISMA-based systematic review methodology for (i) identifying barriers to the application of blockchain in the CSCM and (ii) laying down an effective and impactful research agenda for future scholars. The PRISMA protocol was initially developed in the medical sciences (Doran et al., 2022), and later its use has extended to the discipline of management and its related fields (Pellegrino et al., 2024).

Initially, we searched for academic records that appeared in peer-reviewed journals from 2015 onwards, as the domain under review (i.e., CSCM and blockchain adoption) is a recent phenomenon. To enhance the quality of our search results, we used the three most prominent and largest academic databases, namely Scopus, Google Scholar, and Web of Science. These databases are recognized for their comprehensive coverage and advanced search capabilities, leading to the retrieving of data in an efficient and timely manner (Bonab et al., 2023). This multiple database-based search approach is in line with the prior reviews by Dawkins et al. (2019) and Esfandiar et al. (2022). Google Scholar was used as a supplementary source rather than the primary database because of its broad and dynamic indexing characteristics. Journal impact factor was used as a screening criterion to exclude irrelevant studies published in specialized journals with lower citation metrics. To mitigate this concern, backward and forward snowballing techniques were employed to capture seminal contributions omitted by the database search. Following recommendations for systematic reviews using Google Scholar, only the first ten pages of search results (approximately 100 records sorted by relevance) were screened, as the relevance of results substantially declines beyond this point. Furthermore, backward and forward snowballing techniques were employed to capture seminal studies that may have been omitted due to the dynamic indexing nature of Google Scholar. The search string was as follows:

TITLE-ABS-KEY(("blockchain" OR "block chain" OR "distributed ledger" OR "distributed ledger technology" OR "DLT") AND ("circular supply chain management" OR "circular supply chain*" OR "circular economy" OR "closed-loop supply chain*" OR "sustainable supply chain*" OR "supply chain management") AND ("barrier*" OR "challenge*" OR "barrier*" OR "obstacle*" OR "adoption" OR "implementation")) AND PUBYEAR > 2018 AND (LIMIT-TO(LANGUAGE, "English")) AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO(DOCTYPE, "re")).

A total of 2437 articles were found in this stage from the databases collectively; then, we subsequently advanced to the screening phase. The following table provides an overview of the keywords, inclusion and exclusion criteria for the systematic review (Table 1). After applying all the parameters, the final dataset comprised 22 papers critically examining the barriers to blockchain adoption in CSCM (Fig. 1).

Table 1: Inclusion and exclusion criteria

Keywords	**Inclusion criteria**	**Exclusion criteria**
"circular supply chain management", "circular economy", "supply chain", "blockchain", and "distributed ledger"	(1) only studies from subject areas such as business, economics, management, accounting, econometrics, and finance (2) only reviews and articles (3) English language journal articles (4) articles obtained through snowballing technique (5) articles focusing on barriers of blockchain adoption in CSCM	(1) non-peer-reviewed publications (e.g., working papers, conference proceedings). (2) Studies lacking sufficient methodological detail or relevance to the research objectives

Further, 12 additional articles were included through the snowballing technique (Freixanet, 2022), wherein forward and backward searches were conducted in the previously included articles. The authors had several discussions and deliberations on the inclusion of articles and ultimately attained an inter-rater reliability score of 92%, which is significantly above the acceptable threshold of 80% (Belur et al., 2021). Ultimately, using the final dataset of 34 articles, the authors conducted the content analysis (Gaur & Kumar, 2018) using R Studio (Version 4.3.1) with the Bibliometrix package and its Biblioshiny interface. An inductive thematic analysis technique given by Braun & Clarke (2006), wherein the procedure of "familiarizing with qualitative data, i.e., article texts" (Lim et al., 2022, p. 422) was executed. Fig. 1 illustrates the summary of the four-pronged PRISMA-compliant review procedure.

This study systematically reviewed the existing research on how blockchain technology is used in CSCM, with a special focus on the barriers to its adoption. A co-occurrence analysis of author keywords was conducted using the full-counting method, where each occurrence of a keyword was assigned equal weight. To improve interpretability, a minimum occurrence threshold of two was applied, and only the top 30 most frequently occurring keywords were included in the network visualization (Fig. 2). The most influential journals and prolific authors were generated using the performance analysis functions available in Bibliometrix.

The network shows two main groups (clusters) in the research:

- The first cluster focuses on sustainability, the circular economy, barrier analysis, dynamic capabilities, and blockchain technology. It can be inferred that majority of research links the challenges of adopting blockchain with wider goals like making supply chains more sustainable and circular. Methods like fuzzy-DEMATEL and network theory are often used to study and prioritize these barriers in a structured way.
- The second cluster focuses more on technology-related topics. Important keywords here are trustworthiness, privacy, distributed ledger, smart contracts, scalability, and cyber resilience. This indicates that many barriers are technical, especially issues related to security and trust.

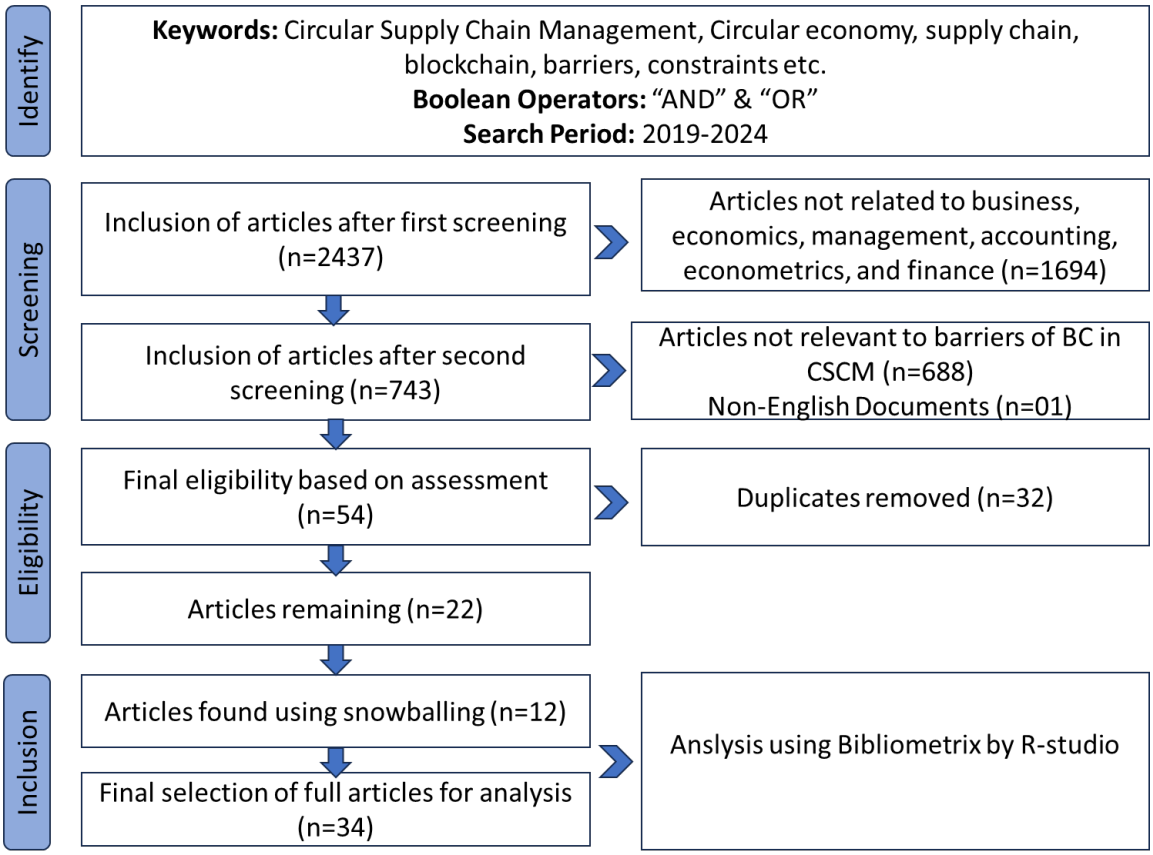


Fig. 1: Systematic review procedure using PRISMA protocol

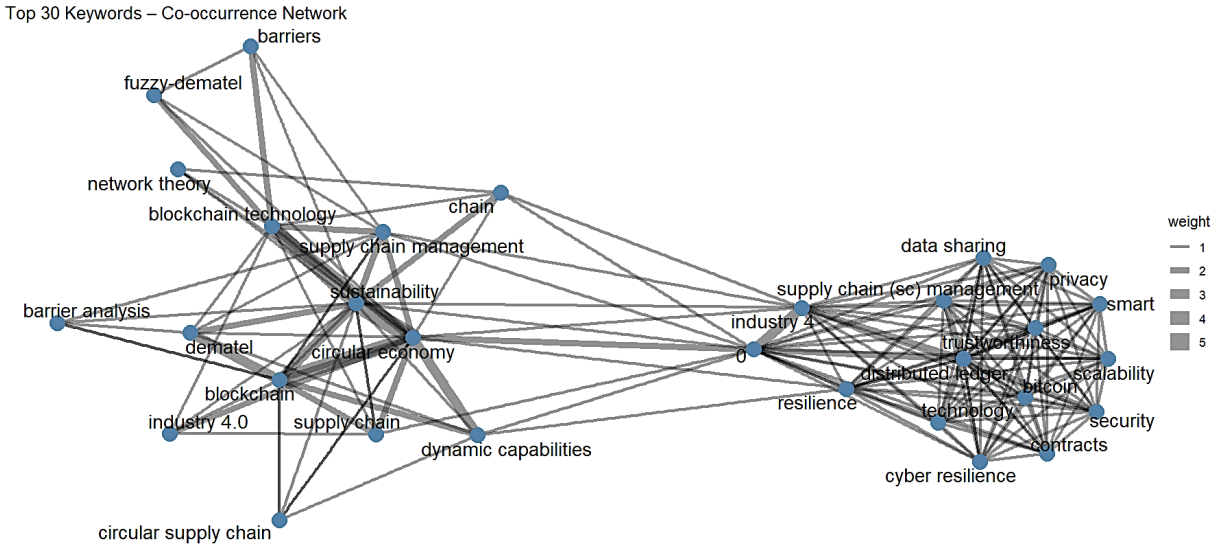


Fig. 2: Co-occurrence network with top 30 keywords

The strength and thickness of the connecting lines between keywords (based on how often they appear together) show that sustainability, circular economy, and blockchain technology are the most discussed topics (Fig. 2). Barrier analysis is closely linked with methods like fuzzy-DEMATEL and DEMATEL, showing a trend in how researchers are studying these issues. Notably, the keyword "Industry 4.0" connects the two groups. This suggests that researchers do not see blockchain barriers

alone, but as part of the larger digital transformation happening in supply chains. The cluster visualization shows that barriers can be divided into three main groups:

- **Technological Barriers**: Problems like limited scalability, difficulties in making different systems work together (interoperability), lack of common standards, and high costs of setting up blockchain solutions are major challenges.
- **Organizational Barriers**: Many firms face issues such as lack of support from top management, resistance to change within the organization, and low awareness and knowledge about blockchain.
- **External and Regulatory Barriers**: Outside factors like unclear legal rules, concerns about data privacy, and lack of trust among supply chain partners also act as major barriers.

The timeline analysis shows that earlier studies (before 2020) mainly focused on checking if blockchain could work technically, through proof-of-concept studies. More recent studies (after 2020) are focusing on bigger issues like scaling up blockchain solutions, developing proper regulations, and building trust between companies. This shift shows that researchers are now giving more attention to real-world challenges in adoption, not just the technology itself.

From the journal distribution (Fig. 3), it is clear that leading journals like *Business Strategy and the Environment, International Journal of Production Research*, *Supply Chain Management: An International Journal*, and *Computers & Industrial Engineering* have published the most important studies in this area. This shows that blockchain adoption barriers in CSCM are an important and growing research area, receiving strong attention from high-quality, peer-reviewed journals. Sarki, J. is the leading author contributing 6 publications to the literature on barriers to blockchain adoption in CSCM followed by Kouhizadeh, M. with 4 publications and Kumar, S. with 3 publications (Fig. 4).

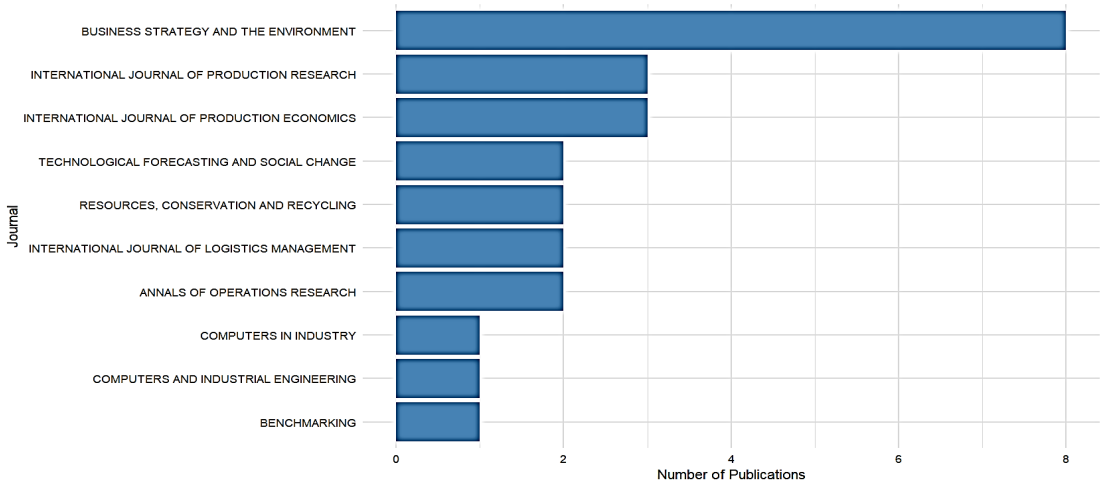


Fig. 3: Top 10 Journals

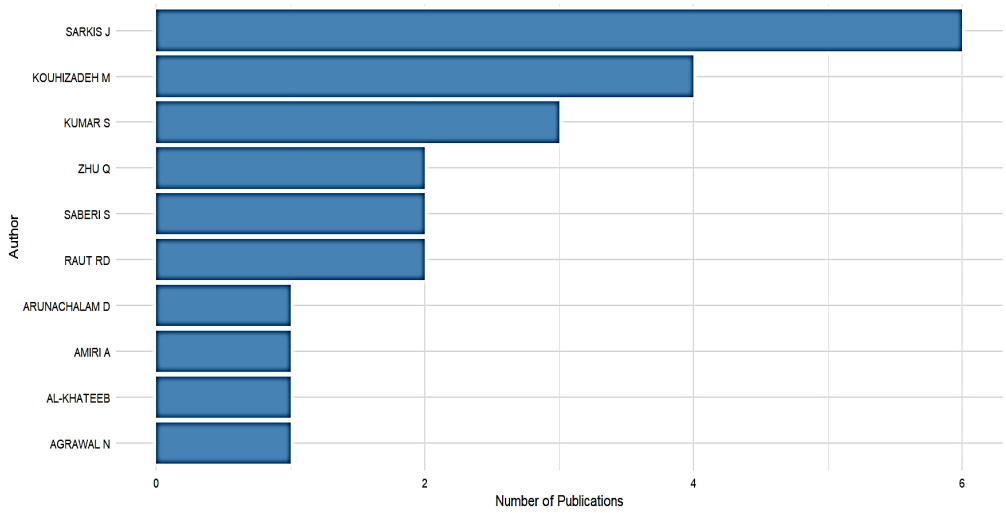


Fig 4: Top 10 most Authors

3. Total Interpretive Structural Modeling Methodology

After conducting a systematic literature review, the primary purpose of this research study is to construct a TISM-based model to examine the contextual relationships among the key influencing barriers to blockchain adoption for CSCM and to understand the relationships among them. The study also classifies the key barriers to blockchain adoption into driving and dependent categories, enabling an assessment of the strength of their interrelationships through MICMAC analysis. TISM technique is the extension of ISM and has been utilized by many researchers to develop structural model and examine contextual relationships among different barriers (Talib & Rahman, 2020).

3.1 Identification of barriers to Blockchain adoption for CSCM

The identification of barriers to blockchain adoption for CSCM was achieved through a comprehensive review of the existing literature, which identified 18 barriers, followed by a collaborative brainstorming session. The brainstorming session included three academics having specialization in supply chain and blockchain research and two industry executives who were involved in managing logistics and supply chain in their respective organizations. The experts evaluated each barrier using four criteria: (i) direct relevance to blockchain adoption in CSCM, (ii) frequency of occurrence in the reviewed literature, (iii) conceptual distinctiveness from other barriers, and (iv) suitability for inclusion in the TISM framework. Based on consensus, three barriers were excluded because they were either insufficiently represented in the literature, conceptually redundant, or indirect antecedents of the retained barriers (Lack of Digital Infrastructure, Resistance to Change and Accuracy Issues). Consequently, the final model comprised 15 barriers that were considered most relevant to understanding blockchain adoption challenges in CSCM. Based on the outcome of brainstorming session, 15 barriers were filtered out and selected for this study as presented in Table 2.

The transferability of these barriers is theoretically justified because CSCM, similar to healthcare, tourism, and other multi-actor systems, requires collaboration among independent stakeholders, secure information exchange, interoperability among heterogeneous information systems, trust in shared data, and compliance with regulatory requirements. For example, privacy concerns in healthcare stem from the need to protect sensitive patient information, whereas in CSCM, firms are reluctant to disclose proprietary information regarding suppliers, product composition, reverse logistics processes, and recycling practices. Although the information being protected differs, the underlying barrier concerns regarding data privacy and security in a distributed ledger environment, is fundamentally the same.

Table 2: List of Barriers of blockchain in CSCM

Barriers	***Relevance and Transferability to CSCM***	***Representative papers***
Security and Privacy (B1)	Privacy concerns may discourage firms from participating in blockchain-enabled circular ecosystems.	Azzi et al. (2019); Gupta et al. (2024); Singh & Kumar (2024); Yadav et al. (2023)
Interoperability/Lack of Standardization in the Blockchain (B2)	CSCM involves multiple actors, including manufacturers, recyclers, logistics providers, and remanufacturers, requiring seamless information exchange and system integration.	Benabdellah et al. (2023); Ghode et al. (2020); Gupta et al. (2024); Kaur et al. (2024); Kumar & Barua (2023)
Scalability and Immaturity of Technology (B3)	Blockchain-enabled CSCM often generates large volumes of product lifecycle and traceability data. Scalability limitations can therefore restrict the effectiveness of circular supply chain operations.	Acikgoz et al. (2024); Anguiano & Parte (2024); Balci & Surucu-Balci (2021); Kaur et al. (2024); Kouhizadeh et al. (2021)
Immutability (B4)	CSCM frequently involves dynamic product information, returns, remanufacturing, and recycling processes.	Kouhizadeh et al. (2023); Yavaprabhas et al., 2024); Yadav et al. (2023)
Financial Barriers (B5)	CSCM initiatives, particularly among SMEs, often face resource barriers. The costs of infrastructure, integration, and employee training may significantly impede blockchain adoption.	Al-Emran (2023); Al-Sharafi et al. (2023); Benabdellah et al. (2023); Samadhiya et al. (2024); Yadav et al. (2023); Zekhnini et al. (2022)
Lack of Top Management Commitment/Support (B6)	Blockchain-enabled CSCM requires substantial organizational change, resource allocation, and cross-functional coordination, making top management commitment essential.	Acikgoz et al. (2024); Agarwal et al. (2024)
Lack of Expertise and Knowledge (B7)	Effective implementation of blockchain-enabled traceability, resource recovery, and circular business models requires technical and managerial expertise that many CSCM organizations currently lack.	Agarwal et al. (2024); Anguiano & Parte (2024); Kouhizadeh et al. (2020); Mohammed et al. (2023); Tripathi et al. (2023)
Cultural Differences (B8)	CSCM ecosystems comprise heterogeneous actors with diverse sustainability priorities, operational cultures, and governance practices, making cultural compatibility a critical requirement.	Benabdellah et al. (2023); Farooque et al. (2020); Kouhizadeh et al. (2023); Salcedo & Gupta (2021); Shukla et al. (2024)
Lack of Coordination and Collaboration (B9)	CSCM inherently depends on collaboration among manufacturers, logistics providers, recyclers, remanufacturers, and waste management agencies. Poor coordination directly undermines circular information flows and resource recovery processes. It refers to the absence of operational mechanisms, governance structures, and collaborative processes necessary for implementing blockchain across organizational boundaries.	Erol et al. (2022); Kaur et al. (2024); Kouhizadeh et al. (2021); Saberi et al. (2019); Yadav et al. (2023); Yadav et al. (2020); Kostić & Sedej (2022).
Lack of Trust Among Supply Chain Partners (B10)	Blockchain-enabled CSCM requires firms to share sensitive operational and environmental information. Lack of trust reduces willingness to participate in collaborative circular ecosystems. It reflects relational concerns regarding information sharing and perceived risks associated with blockchain-enabled transparency	Agarwal et al. (2024); Esmaeilian et al. (2020); Ganguly (2024); Xie et al. (2023); Zekhnini et al. (2022)
Lack of Government Regulations (B11)	CSCM requires legal frameworks governing data ownership, digital traceability, environmental compliance, and cross-organizational information exchange. Regulatory uncertainty therefore directly affects blockchain adoption.	Balci & Surucu-Balci (2021); Esmaeilian et al. (2020); Gupta et al. (2024)
Environmental Concerns Related to	Since CSCM seeks to achieve environmental sustainability and circular economy objectives, energy-intensive blockchain applications may	Expert opinion, Yadav et al. (2023)

Blockchain Energy Consumption (B12)	create a paradox between technological adoption and sustainability goals.	
Lack of Rewards (B13)	Circular supply chains require substantial investments in digital infrastructure and collaborative initiatives. Inadequate incentives reduce firms' motivation to adopt blockchain-enabled CSCM practices.	Kouhizadeh et al. (2021); Wang et al. (2019)
Lack of External Stakeholders' Involvement (B14)	CSCM ecosystems require support from regulators, environmental agencies, certification bodies, and technology providers to establish standards, incentives, and governance mechanisms necessary for blockchain diffusion. It captures deficiencies in institutional support arising from limited engagement of regulators, industry associations, technology providers, NGOs, and other ecosystem actors that influence the legitimacy and diffusion of blockchain technologies.	Wang et al. (2019); Rugeviciute & Mehrpouya (2019)
Lack of Early Adopters (B15)	The absence of pioneering firms limits knowledge spillovers, reduces confidence in blockchain applications, and delays the diffusion of blockchain-enabled circular supply chain practices.	Böhmecke-Schwafert (2024)

Source: *Compiled by authors*

3.2. Data collection process

The authors contacted a panel of nine blockchain and supply chain experts comprising five academics/researchers, and four industry practitioners with experience in implementing blockchain initiatives. The expert panel comprised highly qualified individuals with a Master's degree or higher, along with extensive professional experience of approximately 10-15 years in their respective fields (Table 3).

Table 3: Profile of Experts Participating in TISM Development

Expert Code	Background	Area of Expertise	Exp (years)
E1	Professor, Public University	Supply Chain Management and Sustainability	15
E2	Professor, Public University	Blockchain and CE	13
E3	Associate Professor	Supply Chain Analytics	12
E4	Associate Professor	Operations and Blockchain Applications	11
E5	Researcher/Consultant	CE and Sustainable Supply Chains	10
E6	Supply Chain Manager	Logistics and Technology Integration	15
E7	Operations Manager	Digital Supply Chain Transformation	13
E8	Blockchain Consultant	Blockchain Implementation and ERP Integration	12
E9	Sustainability Manager	CSC and Reverse Logistics	11

4. TISM Modelling

In applying TISM to assess the key barriers and map the relationships among them, the experts were presented with 15 barriers of blockchain adoption for CSCM. To clearly explain the causal relationships among the barriers, the contextual link is explicitly defined as follows: "Barrier 1 exerts an influence on Barrier 2."

4.1 Structural Self-interaction matrix

To identify the relationships among the barriers, the same experts as those mentioned in Section 3.1 were invited to complete the pairwise interaction matrix among the barriers. To express the direction

and nature of relationships among the barriers, four symbols (V, A, X, and O) have been used to denote the relationship between two barriers. The self-interaction matrix (SSIM) is shown in Table 4. Finally, the relationships were finalized based on the consensus of the group and for the relationships where no consensus was reached, the majority opinion was considered.

Table 4: Structural Self-Interaction Matrix (SSIM)

Code	Blockchain Adoption Barrier	B 15	B 14	B 13	B 12	B 11	B 10	B 9	B 8	B 7	B 6	B 5	B 4	B 3	B 2	B 1
B1	Security and Privacy	A	A	A	O	A	A	A	A	A	A	A	V	O	X	-
B2	Interoperability issues / Lack of Blockchain Standardization	A	A	O	O	A	A	A	A	A	O	A	O	V	-	X
B3	Scalability Issues	O	A	O	O	A	A	A	O	A	A	A	O	-	A	O
B4	Immutability	A	A	O	O	A	O	A	A	O	A	A	-	O	O	A
B5	Financial constraints	A	A	A	A	O	O	O	O	X	A	-	V	V	V	V
B6	Lack of top management commitment/ support	A	A	O	A	A	O	O	V	V	-	V	V	V	O	V
B7	Lack of expertise and knowledge	O	A	A	O	A	A	A	X	-	A	X	O	V	V	V
B8	Cultural differences	A	O	O	A	O	A	A	-	X	A	O	V	O	V	V
B9	Lack of coordination and collaboration	A	A	O	O	A	X	-	V	V	O	O	V	V	V	V
B10	Lack of trust among supply chain partners	A	A	A	O	A	-	X	V	V	O	O	O	V	V	V
B11	Lack of Government regulations	V	O	V	V	-	V	V	O	V	V	O	V	V	V	V
B12	Environmental Concerns	O	A	O	-	A	O	O	V	O	V	V	O	O	O	O
B13	Lack of rewards	X	A	-	O	A	V	O	O	V	O	V	O	O	O	V
B14	Lack of external stakeholders' involvement	V	-	V	V	O	V	V	O	V	V	V	V	V	V	V
B15	Lack of Early Adopters	-	A	X	O	A	V	V	V	O	V	V	V	O	V	V

***V:** Barrier i influences or leads to Barrier j (i → j),j; **A:** Barrier j influences or leads to Barrier i (j → i); **X:** Barriers i and j influence each other (i ↔ j); and **O:** Barriers i and j are unrelated and do not influence each other*

4.2 Reachability matrix (RM) and transitivity assessment

Following the established rules, the initial RM of the barriers of blockchain adoption was developed. The initial RM, derived from interpretations V, A, X and O relationships, underwent a transitivity assessment. This process uncovered several indirect relationships, which were identified through a transitivity analysis. Table 5 displays the final RM showing transitivity links by 1*. Driving power and dependence power of the barriers were determined by summing the occurrences of 1s in their corresponding rows and columns.

Table 5: Final Reachability Matrix

Code	Blockchain Adoption Barrier	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14	B 15	Dr Pw
B1	Security and Privacy	1	1	***1****	1	0	0	0	0	0	0	0	0	0	0	0	**4**
B2	Interoperability issues / Lack of Blockchain Standardization	1	1	1	***1****	0	0	0	0	0	0	0	0	0	0	0	**4**
B3	Scalability Issues	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
B4	Immutability	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**1**
B5	Financial barriers	1	1	1	1	1	0	1	***1****	0	0	0	0	0	0	0	**7**
B6	Lack of top management commitment/ support	1	***1****	1	1	1	1	1	1	0	0	0	0	0	0	0	**8**

B7	Lack of expertise and knowledge	1	1	1	***1****	1	0	1	1	0	0	0	0	0	0	0	**7**
B8	Cultural differences	1	1	***1****	1	***1****	0	1	1	0	0	0	0	0	0	0	**7**
B9	Lack of coordination and collaboration	1	1	1	1	***1****	0	1	1	1	1	0	0	0	0	0	**9**
B10	Lack of trust among supply chain partners	1	1	1	***1****	***1****	0	1	1	1	1	0	0	0	0	0	**9**
B11	Lack of Government regulations	1	1	1	1	***1****	1	1	***1****	1	1	1	1	1	0	1	**14**
B12	Environmental Concerns	***1****	***1****	***1****	***1****	1	1	***1****	1	0	0	0	1	0	0	0	**9**
B13	Lack of rewards	1	***1****	***1****	***1****	1	***1****	1	***1****	***1****	1	0	0	1	0	1	**12**
B14	Lack of external stakeholders' involvement	1	1	1	1	1	1	1	***1****	1	1	0	1	1	1	1	**14**
B15	Lack of Early Adopters	1	1	***1****	1	1	1	***1****	1	1	1	0	0	1	0	1	**12**
	Dependence Power	**13**	**13**	**14**	**14**	**11**	**6**	**11**	**11**	**6**	**6**	**1**	**3**	**4**	**1**	**4**	

4.3 Level's partitioning

To identify the relative importance of each barrier, the level partitioning technique was utilized. The final partitioning result of the barriers is shown in Table 6. In this study, six levels of barriers were identified. "Scalability issues (B3)" and "Immutability challenges (B4)" were identified as the top-level barriers, whereas "Lack of government regulations (B11)" and "Lack of external stakeholders (B14)" were found to be the most important bottom-level barriers.

Table 6: Partitioning the final reachability matrix into different levels (Iteration I to VI)

Barrier Code	Reachability set R(Bi)	Antecedent set A (Bi)	Intersection set R(Bi)∩A(Bi)	Level
B1	B1 B2 B3 B4	B1 B2 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B1 B2	II
B2	B1 B2 B3 B4	B1 B2 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B1 B2	II
B3	B3	B1 B2 B3 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B3	I
B4	B4	B1 B2 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B4	I
B5	B1 B2 B3 B4 B5 B7 B8	B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B5 B7 B8	III
B6	B1 B2 B3 B4 B5 B6 B7 B8	B6 B11 B12 B13 B14 B15	B6	IV
B7	B1 B2 B3 B4 B5 B7 B8	B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B5 B7 B8	III
B8	B1 B2 B3 B4 B5 B7 B8	B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15	B5 B7 B8	III
B9	B1 B2 B3 B4 B5 B7 B8 B9 B10	B9 B10 B11 B13 B14 B15	B9 B10	IV
B10	B1 B2 B3 B4 B5 B7 B8 B9 B10	B9 B10 B11 B13 B14 B15	B9 B10	IV
B11	B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B15	B11	B11	VI
B12	B1 B2 B3 B4 B5 B6 B7 B8 B12	B11 B12 B14	B12	V
B13	B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B13 B15	B11 B13 B14 B15	B13 B15	V
B14	B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B12 B13 B14 B15	B14	B14	VI
B15	B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B13 B15	B11 B13 B14 B15	B13 B15	V

4.4 Interpretive logic-knowledge base matrix

TISM requires that each contextual relationship be clearly and logically explained, including a justification of how the relationship operates. Every direct and meaningful connection is then interpreted through a logical rationale by the group of experts, and an interpretation statement was written for each link. Finally, the interpretive matrix is constructed based on expert-provided

explanations of direct relationships and the significant transitive links identified. Table 7 presents the resulting interpretive matrix along with the interactions. The matrix represents the principal distinction between TISM and conventional ISM because it supplements the structural hierarchy with expert-derived interpretations of interrelationships among barriers.

Table 7. Interpretive Logic–Knowledge Base Matrix of the Final TISM Model

Link	Interpretation
B11 → B13	Inadequate government regulations limit the development of incentive schemes, subsidies, and policy frameworks that encourage firms to adopt blockchain technologies.
B11 → B15	Regulatory uncertainty increases perceived risks and discourages organizations from becoming early adopters of blockchain-enabled CSCM systems.
B11 → B12	Absence of environmental regulations and sustainability standards reduces pressure to adopt environmentally responsible blockchain solutions.
B14 → B13	Limited participation of external stakeholders, such as regulators, technology providers, and industry associations, restricts the creation of rewards and incentive mechanisms for blockchain adoption.
B14 → B15	Lack of support from industry bodies and technology ecosystems reduces organizational confidence and willingness to become early adopters.
B14 → B12	External stakeholders often promote environmental awareness and sustainability initiatives; their absence weakens environmental considerations in blockchain adoption.
B12 → B6	Environmental concerns increase managerial uncertainty regarding the energy consumption and sustainability implications of blockchain technologies, thereby reducing top management commitment.
B12 → B5	Environmental concerns often require investment in greener blockchain infrastructure and energy-efficient technologies, thereby increasing financial requirements and perceived cost barriers.
B13 → B10	Lack of economic rewards and incentives discourages organizations from participating in collaborative blockchain ecosystems and reduces trust in the long-term benefits of adoption.
B13 → B1	Lack of financial rewards and incentive mechanisms discourages organizations from investing in advanced cybersecurity infrastructure and privacy-preserving blockchain solutions
B15 → B9	A limited number of early adopters reduces demonstration effects and network externalities, thereby weakening coordination and collaborative initiatives among supply chain actors.
B15 → B1	A limited number of early adopters reduces practical evidence regarding blockchain security and privacy, thereby increasing organizational concerns about protecting sensitive supply chain information
B6 → B7	Insufficient top management commitment restricts investments in employee training, technological capability development, and blockchain knowledge acquisition.
B9 → B7	Poor collaboration and information sharing among supply chain partners impede collective learning and knowledge transfer regarding blockchain implementation.
B10 → B7	Low levels of trust discourage information sharing and inter-organizational learning, resulting in inadequate blockchain expertise.
B7 → B8	Insufficient knowledge regarding blockchain capabilities increases resistance to change and reinforces cultural differences among supply chain actors.
B7 → B5	Lack of expertise results in inefficient planning and higher implementation costs, thereby intensifying financial barriers associated with blockchain adoption.
B7 → B1	Insufficient blockchain expertise limits organizations' ability to design secure blockchain architectures and implement appropriate privacy safeguards, increasing security concerns
B5 → B1	Financial constraints limit investments in cybersecurity infrastructure, data protection mechanisms, and privacy-preserving technologies.
B5 → B2	Limited financial resources constrain investments in interoperability standards and integration capabilities with existing ERP systems.
B8 → B1	Cultural differences generate divergent perceptions regarding data ownership, transparency, and information sharing, thereby increasing security and privacy concerns.
B8 → B2	Differences in organizational culture and operating practices hinder the adoption of common blockchain standards and interoperable processes.
B2 → B3	As the number of participating organizations and transactions increases, these integration inefficiencies limit the blockchain network's ability to scale effectively, thereby exacerbating scalability issues.

B1 → B3	Security and privacy requirements often necessitate additional encryption and verification mechanisms, which increase computational complexity and reduce blockchain scalability.
B1 → B4	Security and privacy concerns necessitate immutable records and tamper-proof data structures, strengthening the challenges associated with blockchain immutability.

With the final RM presented in Table 6, replacing the nodes with barriers of blockchain adoption, and information obtained from interpretive matrix, Table 7, the final TISM model for barriers to blockchain adoption for CSCM was developed, as depicted in Fig. 5. Finally, MICMAC analysis was performed, resulting in driving and dependence diagram to assess the relative importance and interdependencies between the identified barriers of blockchain adoption (Singh & Singla, 2022). Following conventional MICMAC practice, the average driving power and average dependence power were used as threshold values to distinguish between marginal and significant influence. Barriers located near the threshold were interpreted with support from expert judgment and their structural position in the TISM hierarchy. This method visually groups barriers based on their driving and dependence power values derived from the final RM. Based on these results, MICMAC analysis was then conducted, with the outcomes displayed in Fig. 6, where the X-axis denotes dependence power and the Y-axis represents driving power. In MICMAC analysis shown in Fig. 6, the second cluster is of the "resultant barriers" and they are categorized by their low driving power but marked dependence on other barriers in the system under consideration. Such barriers are highly dependent on the performance of barriers below them in the hierarchy. This research highlights four dependent barriers. They are Security and privacy concerns (B1), Interoperability issues (B2), Scalability issues (B3) and Immutability challenges (B4).

The third cluster is "interactive barriers" that have significant driving power coupled with high dependency making them dynamic barriers that can impact the system performance. This research has identified three interactive barriers that play a pivotal role. They are: Financial constraints (B5), Lack of knowledge/expertise about blockchain (B7), and Cultural differences (B8). These barriers lie near the center of the matrix and may belong to different clusters; however, the authors have categorized them within the third cluster.

The fourth cluster is "core barriers/root barriers" possessing strong driving influence while exhibiting low dependence, thereby acting as key elements that stimulate or influence other barriers. In the context of this study, eight driver barriers have been identified: Lack of top-management commitment (B6), Lack of collaboration and coordination in SC (B9), Lack of trust among SC members (B10), Lack of government regulations (B11), Environmental concerns related to blockchain energy consumption (B12), Lack of rewards (B13), Lack of external stakeholders (B14) and Lack of early adopters (B15).

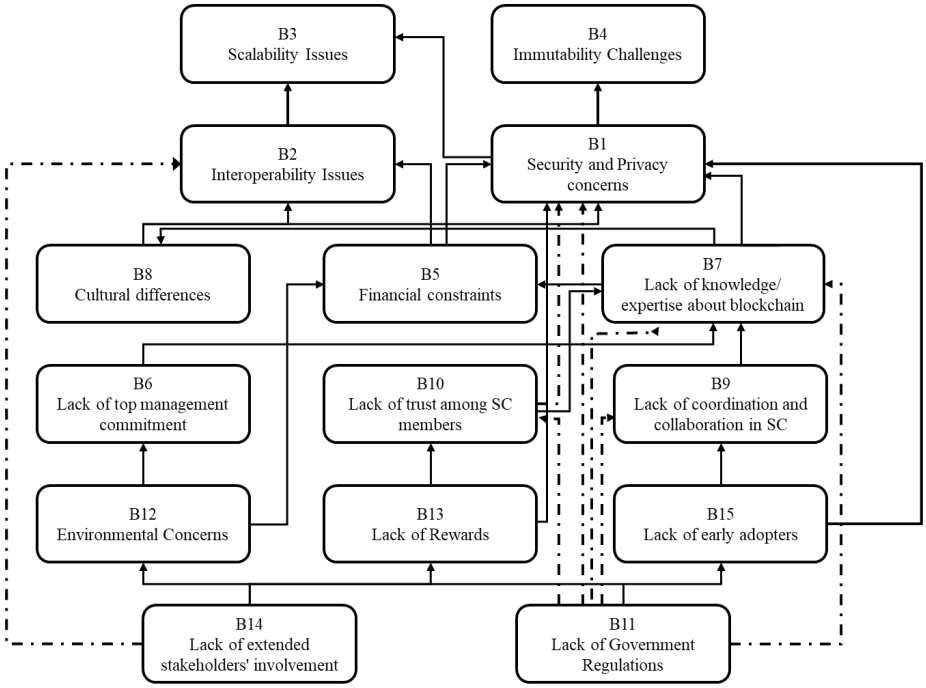


Fig 5: Final TISM based Model for the barriers of blockchain adoption for CSCM

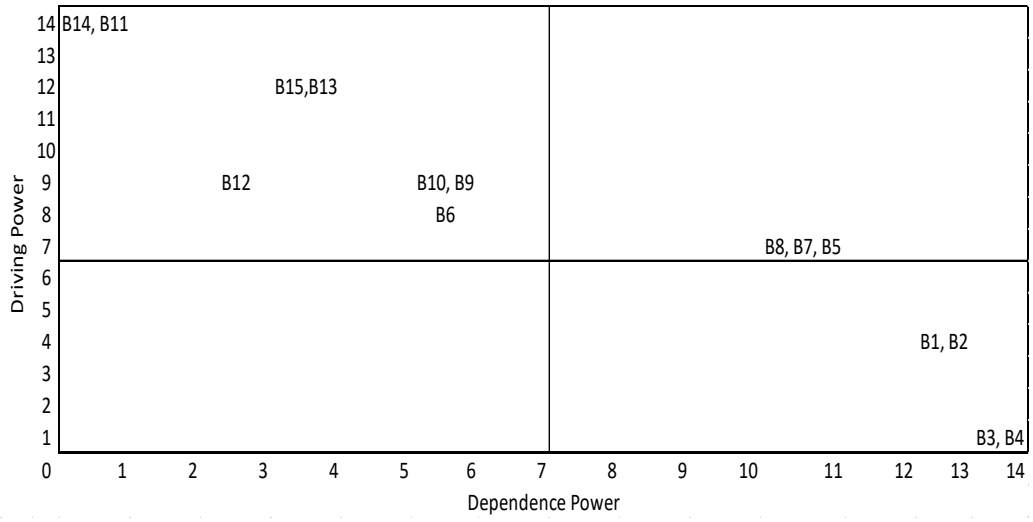


Fig 6: MICMAC analysis

5. Discussion

The TISM hierarchy indicates that blockchain adoption barriers in CSCM are hierarchical and interdependent rather than independent. At Level VI, lack of government regulations (B11) and lack of external stakeholders' involvement (B14) act as foundational institutional barriers because they determine the availability of standards, incentives, legitimacy, and governance mechanisms necessary for blockchain diffusion. Levels V and IV comprise enabling and organizational barriers that shape managerial commitment, trust, and collaboration. Lack of expertise and knowledge (B7) at Level III serves as a transitional barrier, translating ecosystem and organizational deficiencies into operational challenges. Finally, scalability issues (B3) and immutability challenges (B4), along with security and interoperability concerns, appear at the upper levels because they are highly dependent outcomes arising from deeper institutional and organizational shortcomings. Therefore, addressing root-level barriers is likely to generate cascading improvements in technological adoption outcomes.

The identified barriers constituted the foundation of the TISM model and required careful strategic attention, as they have the potential to affect other barriers. Consequently, the study indicated that effectively managing the core and interactive barriers can mitigate the resultant barriers such as "Scalability issues (B3)" and "Immutability challenges (B4)" of blockchain adoption for CSCM. CSCM integrates circular thinking and the aspects of the circular economy into supply chain management (Meier et al., 2023). The principal objective of CSCM is to establish a “zero-waste supply chain” throughout all supply chain activities within the horizon of all stakeholders, from raw material suppliers to end customers (Dora et al., 2021; Yu et al., 2022). The integration of digitization and circular economy strategies may create implementation challenges due to their divergent organizational and societal aims (Schmidt et al., 2024). A clear strategic direction is crucial for leveraging the benefits of environmental and digital solutions (Ardito et al., 2021; Chawla et al., 2023). By deploying a systematic review methodology (Snyder, 2019) in the hybrid domain (Kraus et al., 2022) of blockchain and CSCM management, the present study identified three categories of barriers to the implementation and use of blockchain in CSCM, i.e., technological barriers, environmental barriers, and organizational barriers.

The lack of standardization across blockchain platforms can prevent seamless interoperability, which is crucial for linking suppliers, manufacturers, and consumers within a circular economy framework (Benabdellah et al., 2023). Additionally, the cost associated with implementing blockchain infrastructure, especially for smaller and medium-sized enterprises (SMEs), constitutes a financial hurdle that can constrain the scalability of blockchain-enabled CSCM systems (Kumar et al., 2022b). Previous research indicates that integrating blockchain within established supply chains often necessitates substantial investment in both technology and training, further complicating adoption (Yadav et al., 2020).

Regulatory uncertainty also poses a significant challenge, particularly in industries that operate under strict compliance regimes. Clear regulatory frameworks governing blockchain use in CSCM, particularly concerning data privacy and environmental standards, will be critical to fostering broader adoption (Schmidt et al., 2024). Addressing these regulatory challenges through coherent policy frameworks will allow blockchain to be implemented more widely without fear of compliance issues (Mustafa et al., 2025). Furthermore, the governance of blockchain platforms must be addressed, ensuring that data integrity is maintained throughout the supply chain to avoid inefficiencies and inaccuracies (Karaduman & Gülhas, 2025). Establishing strong governance structures will help secure stakeholder trust, which is paramount for successfully integrating blockchain technology (Tan & Lee, 2024).

Issues like scalability, adoption complexities, and high energy demands limit the practical implementation (Yadav et al., 2023) of blockchain for CSCM. One major issue is that the decentralized nature of blockchain exposes the network to potential security vulnerabilities, especially if the majority of participants in the supply chain are not technically equipped to manage these risks effectively (Mishra et al., 2023). Furthermore, although blockchain transactions are encrypted, the transparency inherent in many blockchain architectures may increase concerns regarding the visibility of sensitive supply chain information, raising concerns about data privacy and confidentiality (Gupta et al., 2024). Addressing these issues requires robust security protocols and access control mechanisms, which are not yet fully mature in most blockchain implementations (Kumar & Barua, 2023).

6. Conclusion

The findings indicate that security and privacy concerns are closely associated with the challenges of immutability in blockchain-enabled CSCM. Organizations often struggle to balance the benefits of immutable records with the need to protect sensitive information, comply with data governance regulations, and manage errors or updates in dynamic supply chain environments. Consequently, security and privacy concerns complicate the practical implementation of immutable blockchain systems instead of undermining the fundamental concept of immutability itself. The heterogeneous systems operating across the supply chain

are often incompatible, resulting in inefficiencies that impede scalability. The lack of standardization results in fragmented implementation. Another significant barrier, particularly for SMEs, is the high cost of implementation; therefore, adoption remains economically challenging. Governments can facilitate blockchain adoption in CSCM through supportive regulations and financial incentives.

Another barrier is limited technical expertise, which restricts the effective adoption of blockchain. Due to limited understanding and familiarity with technology, resistance to change is a common barrier. In resistance to change, culture also plays a vital role, particularly in emerging economies. The reluctance to share information and the blockchain's idea of decentralization are in conflict. This contributes to low levels of trust among supply chain partners and discourages timely and relevant information sharing. This contributes to concerns regarding data reliability for blockchain implementation across the system.

The lack of collaboration among supply chain partners leads to poor data adoption, low levels of trust, fragmented data, and thus hinders blockchain usage. Therefore, supply chain partners require stronger coordination to promote collective capacity building for blockchain adoption. Another important blockchain-related barrier is the absence of supportive regulations from governments. These fragmented adoption practices result in uneven implementation across supply chain functions, thereby weakening implementation effectiveness across supply chain functions.

Concerns about the energy consumption of blockchain technology are also deterring firms from adopting it. The absence of carbon-offset mechanisms and supportive government regulations, together with concerns regarding environmental implications, poses a challenge to blockchain adoption in CSCM. Addressing these environmental concerns can reassure stakeholders about sustainability. Also, the absence of financial or non-financial incentives demotivates supply chain stakeholders from investing in blockchain technology, especially when the risks are high. Potential adopters are also hesitant due to limited success stories and resistance to new blockchain technologies. Providing incentives and sharing success stories can help stakeholders feel supported and more confident in their investment decisions.

On the other hand, external stakeholders such as customers and regulators are not pressuring the supply chains to adopt blockchain in their systems, thereby weakening the momentum to change. Recognizing the role of external stakeholders may enhance their willingness to participate in blockchain-enabled CSCM initiatives. The issue of technical workforce availability, trained staff, and infrastructure is also limiting external stakeholders' willingness, and, as a result, organizations may find it difficult to clearly evaluate the potential benefits of adoption. Without addressing key issues such as security, privacy, and information accuracy, stakeholder apathy toward data governance and transparency is likely to persist. Organizational resistance may persist, thereby limiting adoption and exacerbating scalability challenges. Efficiency and effectiveness will remain challenges, and blockchain's potential cannot be fully leveraged.

7. Practical Implications

The findings suggest that blockchain adoption in CSCM requires coordinated interventions from multiple stakeholders. For policymakers and regulators, the priority should be to establish clear regulatory frameworks governing data ownership, interoperability, digital traceability, and environmental compliance. Governments may also introduce financial incentives, tax benefits, and regulatory sandboxes to encourage experimentation and reduce adoption risks. Government bodies and stakeholders should develop and disseminate proof-of-concept projects, pilot implementations, and case studies to encourage early adopters, thereby building confidence throughout the supply chain ecosystem. Industry-specific alliances and consortia can facilitate trust, reduce costs, enhance transparency, and promote standardization across the entire supply chain. Sustainable designs and energy-efficient protocols need to be prioritized to address blockchain's environmental concerns.

For managers, consortium-based blockchain governance mechanisms should be developed to promote trust, information sharing, and collaborative decision-making among circular supply chain partners. Managers should adopt phased implementation strategies, beginning with pilot projects in

areas such as product traceability, reverse logistics, and recycling operations before scaling blockchain deployment across the supply chain.

For SMEs, resource barriers can be mitigated through collaborative blockchain platforms, shared digital infrastructure, and participation in industry consortia. SMEs should prioritize capability development through employee training and strategic partnerships with technology providers and larger firms. For technology developers, efforts should focus on designing interoperable, scalable, and energy-efficient blockchain solutions. The development of shared standards, modular architectures, and green consensus mechanisms can reduce implementation complexity and address scalability and environmental sustainability concerns. For industry associations and external stakeholders, active involvement is required to facilitate standardization, knowledge dissemination, certification, and cross-sector collaboration.

Regulatory bodies need to formulate clear, supportive policies for stakeholders. The focus should not be limited to standardization but also encompass environmental guidelines and legal frameworks for blockchains. Financial subsidies, training initiatives, shared data platforms, etc., are needed to enable greater, meaningful participation by SMEs. To ensure the success of blockchain-enabled CSCM systems, the knowledge and skill gap should be addressed. Government capacity-building programs can enhance stakeholders' digital readiness to address this gap.

8. Limitations and Future Research Directions

This paper uses the SLR and TISM approaches to understand the barriers to blockchain adoption in CSCM. The systematic analysis indicates that the barriers to blockchain adoption in CSCM are complex. They involve sustainability goals, technical challenges, and organizational capabilities. Future studies should examine these areas together, integrating technological and strategic management perspectives to develop stronger frameworks for adoption. The use of the journal impact factor as a screening criterion may have excluded some relevant studies published in specialized journals with lower citation metrics. Future studies may adopt broader journal selection criteria to improve coverage and reduce potential publication bias.

The relationships were analyzed by experts based on informed consensus. These relationships may be further validated through quantitative assessment using graph theory. Furthermore, the underlying relationships and configurations among these variables can be explored in greater detail using approaches such as Qualitative Comparative Analysis (QCA), thereby providing richer insights into their causal dynamics.

Since TISM results are based on subjective expert judgments, they may vary depending on the composition of the expert panel. Given the limited responses from experts and managers, future researchers can use fuzzy theories to mitigate bias in the overall analysis. Additionally, hybrid multi-criteria decision-making approaches can be employed to analyze the identified enablers and quantify the strength and direction of their interrelationships and relative influence. Researchers should carefully consider the conceptual foundations and assumptions underlying different modeling approaches and select methods most appropriate to the study's specific objectives and context.

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Appendix: Articles Included in the Systematic Review (n = 34)

S. No.	Authors (Year)	Database Source*	Industry/Context	Reason for Inclusion	Barrier (s) Extracted
1	Azzi et al. (2019)	Scopus	Supply Chain Management	Discusses blockchain adoption challenges and implementation issues	B1, B2, B10
2	Saberi et al. (2019)	Scopus	Sustainable Supply Chains	Examines blockchain barriers in sustainable SCM	B7, B10, B11
3	Wang et al. (2019)	WoS	Blockchain Adoption	Identifies institutional and adoption barriers	B13, B15
4	Esmaeilian et al. (2020)	Scopus	Circular Economy	Investigates blockchain-enabled circular systems	B5, B11, B12
5	Farooque et al. (2020)	Scopus	Sustainable SCM	Explores ecosystem and stakeholder barriers	B9, B14
6	Ghode et al. (2020)	WoS	Supply Chain Digitalization	Examines technical implementation challenges	B2, B3
7	Yadav et al. (2020)	Scopus	Supply Chain Management	Addresses trust and governance concerns	B10, B11
8	Balci & Surucu-Balci (2021)	Scopus	Blockchain Adoption	Explores cultural and environmental concerns	B8, B12
9	Kouhizadeh et al. (2021)	WoS	Circular Supply Chains	Focuses on CSCM-specific blockchain barriers	B2, B7, B10
10	Salcedo & Gupta (2021)	Scopus	Supply Networks	Examines collaboration and cultural barriers	B8, B9
11	Erol et al. (2022)	WoS	Digital Transformation	Investigates collaboration and trust issues	B9, B10
12	Zekhnini et al. (2022)	Scopus	Sustainable Operations	Discusses security, cost and sustainability challenges	B1, B5, B12
13	Al-Emran (2023)	Scopus	Technology Adoption	Identifies institutional barriers	B11, B14
14	Al-Sharafi et al. (2023)	Scopus	Digital Innovation	Examines ecosystem readiness factors	B11, B14
15	Kumar & Barua (2023)	Scopus	Sustainable Operations	Discusses knowledge and interoperability challenges	B2, B7
16	Mohammed et al. (2023)	WoS	Blockchain Adoption	Investigates capability and financial barriers	B5, B7
17	Tripathi et al. (2023)	Scopus	Digital SCM	Explores resource and expertise constraints	B5, B7
18	Xie et al. (2023)	WoS	Blockchain Ecosystems	Focuses on trust and governance issues	B10, B11
19	Benabdellah et al. (2023)	Scopus	Blockchain Implementation	Examines implementation barriers	B1, B5, B11
20	Kouhizadeh et al. (2023)	Scopus	Circular Economy	Discusses CSCM adoption challenges	B3, B7, B9
21	Yadav et al. (2023)	WoS	CSCM	Examines blockchain barriers in CSCM	B1, B9, B11
22	Acikgoz et al. (2024)	Scopus	Sustainability Transitions	Investigates organizational readiness barriers	B2, B6
23	Agarwal et al. (2024)	Backward Snowballing	Blockchain Readiness	Provides evidence on organizational capabilities	B5, B6, B7
24	Anguiano & Parte (2024)	Backward Snowballing	Digital Traceability	Examines integration and interoperability challenges	B2, B5
25	Böhmecke-Schwafert (2024)	Backward Snowballing	Sustainable Blockchain	Discusses environmental concerns of blockchain	B12
26	Ganguly (2024)	Backward Snowballing	Circular Economy	Addresses sustainability and adoption barriers	B5, B11
27	Gupta et al. (2024)	Backward Snowballing	Blockchain Integration	Examines security and interoperability concerns	B1, B2, B8
28	Kaur et al. (2024)	Forward Snowballing	Sustainable Supply Chains	Investigates technical and collaborative barriers	B2, B3, B9
29	Samadhiya et al. (2024)	Backward Snowballing	Technology Governance	Addresses policy and stakeholder-related barriers	B11, B14
30	Shukla et al. (2024)	Forward Snowballing	Blockchain Ecosystems	Examines collaboration and ecosystem barriers	B9, B14
31	Singh & Kumar (2024)	Forward Snowballing	CSCM Digital Transformation	Discusses adoption and security challenges	B1, B15
32	Yavaprabhas et al. (2024)	Forward Snowballing	Circular Business Models	Examines scalability and expertise barriers	B3, B7
33	Upadhyay et al. (2021)	Backward Snowballing	Sustainable & Circular Supply Chains	Provides insights into blockchain-enabled CSCM adoption	B9, B10, B15
34	Kouhizadeh et al. (2020)	Forward Snowballing	Circular Economy & Supply Chains	Examines blockchain adoption barriers in circular ecosystems	B7