sustainability

Review

Leveraging Blockchain Technology in Supply Chain Sustainability: A Provenance Perspective

Lewis A. Njualem

Department of Information & Decision Sciences, Jack H. Brown College of Business and Public Administration, California State University, San Bernardino, CA 92407, USA; lewis.njualem@csusb.edu

Abstract: Technological advancements in the past few decades have played a critical role in enhancing supply chain management from varied dimensions. While advancements in information technology have significantly improved various facets of the supply chain, supply chain visibility still lags in tracking and tracing capabilities. The disruptive and emergent blockchain technology (BCT) presents enormous potential to address issues of supply chain sustainability. This paper seeks to evaluate the proximity of BCT to resolve provenance issues throughout the supply chain. The research considers the immaturity of BCT alongside limited success stories in supply chain management. It uses a content analysis methodology to examine recent literature about using BCT in supply chain sustainability and provenance. A conceptual model for using BCT to create an enabled, visible, and sustainable supply chain is provided to frame the investigation. Findings reveal that the benefits of BCT have mostly been conceptually demonstrated in the sustainable supply chain literature, but with few practical applications. Moreover, technically driven challenges including scalability and control are still prevalent. It reaffirms the fact that participants within a blockchain enabled supply chain network must be at the same level of knowledge regarding the technology and its functionality. The study also indicates evidence of a growing research interest in the niche, which will eventually bring about solutions to address ongoing challenges faced by BCT in its integration into supply chain management. These findings contribute to the literature about improving the security and utility of supply chain sustainability and provenance by using BCT.

Keywords: sustainable supply chain; blockchain technology; visibility; traceability; provenance

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1. Introduction

Finished goods from a manufacturing perspective generally owe their roots to sourcing from diverse origins, especially now, when globalized supply chains have become increasingly complex and time-sensitive. The issue of provenance for manufactured goods, likewise, has grown exponentially among consumers who are interested in sustainably manufactured products. This challenge is compounded not only because of the expansiveness of contemporary supply chains, but also due to flexible manufacturing options. The attempt by manufacturing operations to leverage economies of scope through substitute raw materials and components further complicates tracking and tracing efforts in the supply chain. A specific finished product may utilize different variants of bills of material (BOM) in the manufacturing process. This is common in the automotive sector, for instance, where dozens of alternative components dominate the mass customization process. Through the commercial information currently at customers' disposal, they cannot effectively ascertain the underlying variety of materials in cars they consider purchasing [1].

To probe the idea of greater source provenance visibility, this study considers three main constructs: supply chain sustainability, supply chain visibility, and blockchain technology. Even though it is common for consumers to focus their attention on environmental aspects of sustainability, supply chain sustainability entails a more holistic scope which considers social and economic factors throughout the value chain of a finished product.

Supply chain sustainability takes on an integrated approach to ensure reliable management of inbound and outbound processes as well as logistics within a supply chain, from an environmental, social, and economic point of view. Supply chain visibility within this context sets the stage for proper assessment of supply chain sustainability. Given technological advancements over the past few decades to enhance communication and visibility across supply chains, areas of supply and demand synchronization have realized significant improvement. Visibility enhances collaboration and trust in relationships with partners and, as such, enables the development of strong relationships with partners and stakeholders [2]. Mechanisms and technological approaches such as radio frequency identification (RFID), serialization, bar codes, and e-pedigree have been deployed to facilitate traceability in diverse industries. However, these solutions are centralized and have serious limitations when it comes to interoperability, privacy, scalability, and security in preventing sabotage in the supply chains [3].

BCT, albeit considered experimental and still risky in some areas of implementation, possesses substantial potential. It has already been highly successful in the financial domain, such as with bitcoin [4], which has attracted interest from a diversity of other application arenas. In the mining and metal industry for instance, BCT entered the industry because of the promise of reducing the need for intermediaries or trusted partners to verify, audit, or certify supply chain information [5]. Security, transparency, and traceability typify primary characteristics and capabilities of BCT that would benefit supply chain visibility. Fundamentally, blockchain is a database with encrypted blocks of data, aligned in a chain to sequentially establish a single, incorruptible source of evolving information. Despite its success in the financial sector, there have been few research efforts to investigate its utilization in other sectors. Additionally, these studies have mostly focused on specific supply chains, especially from an industry perspective, without necessarily considering the effects on the network, which are typical in the contemporary business environment. This research bridges the gap in the supply chain literature as it comprehensively seeks to investigate the potential of BCT in addressing provenance issues related to raw materials, components, and finished goods throughout the value chain. Therefore, the research attempts to answer the following questions:

1. What is the extent to which research has been conducted about block chain technology utilization in supply chain sustainability?
2. What are the currently-known benefits of block chain technology to supply chain visibility?
3. What are the current challenges faced by block chain technology in supply chain provenance?

The research applies a content analysis method to evaluate texts by using key words related to supply chain sustainability, supply chain visibility, traceability, tracking, and blockchain technology. A textual analysis of recent literature will enable the systematic data collection, analysis, and synthesis of key concepts in this area of research. In turn, the findings will help map the current research in this nascent area and forge pathways for subsequent investigation.

2. Literature Review

This section reviews the key research constructs for this study: supply chain visibility, supply chain sustainability, and the BCT context.

2.1. Supply Chain Visibility

As asserted in most of the supply chain management (SCM) literature, supply chain visibility goes beyond tracking of parts, components, and finished products from upstream partners to final consumers. The construct also entails access and transparency to accurate and timely content of relevant information within the supply chain network. Informed decisions are facilitated through the timely access of information among supply chain partners. Many traditional supply chain networks have poor upstream and downstream visibility with little shared information [6]. Consequently, traditional supply chains lack traceability and transparency, which becomes an industry-wide challenge causing painful inefficiency with delays, errors, and increased costs [7]. According to [8], supply chain visibility (SCV) refers to making informed decisions using the timely and accurate exchange of information between participants as materials move in the supply chain. In sharing information between supply chain participants, the process and access to content must be agreed upon due to reasons of competitive advantage and other security related concerns. Ref. [9] defined supply chain visibility (SCV) as the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider of mutual benefit.

The concept of supply chain visibility (SCV) overlaps across several areas of SCM research; hence, there is not yet consensus about the exact definition of SCV [10]. However, these varied viewpoints do converge to some degree around the issue of sustainability. Without an appropriate level of visibility, a sustainable supply chain will find meeting its sustainability objectives challenging [11]. Irrespective of the lens through which SCV is viewed, information technology remains the primary enabler in contemporary supply chain management. Enhancing traceability using complex, modern-day technology is highly sought-after, especially in the pharmaceutical industry. Enterprise applications and cloud-enabled technologies have improved multiple areas of SCV utilization. However, these centralized systems also present limitations as far as the scope of visibility is concerned. Provenance of finished products from a consumer point of view is highly dependent upon effective implementation of SCV, using seamless technologies in the entire network. A broken or incomplete link in the information pipeline will potentially compromise data accuracy and availability. The objectives of a visible and accessible SCV are more aligned with those of the decentralized blockchain technology, which can provide greater traceability, security, and trust. There is considerable room to improve the supply chain in terms of end-to-end traceability, speed of product delivery, coordination, and financing [12], and BCT can be a powerful tool in addressing these issues.

2.2. Supply Chain Sustainability

Sustainability standards have become controversial, fueled by the fact that there is not a widely accepted, unified model to measure sustainability within a diverse global economic network. Sustainability in the global supply chain is receiving significant attention, since over 93 percent of the world's 250 largest firms report on sustainability [13]. The inability to define and acquire sustainability related data in the global supply chain is also a growing concern. An approach ensuring a sustainable supply chain, therefore, must rudimentarily consider proper identification of measurable attributes, which may differ from one supply chain to the next. Beyond the process of identification, attributes need to be categorized based on the principal dimensions of sustainability. In the sustainability literature, the common theme that arises from different definitions presented by researchers and professional organizations is concurrent realization of three dimensions of performance: economic, environmental, and social [14]. The three dimensions are in line with the triple-bottom-line (TBL) principle that considers a sustainable organization as one in which the sustainability evaluation process goes beyond traditional and financial bottom-lines [15]. The evaluation process must be stringent and consider social, environmental, and economic dimensions.

In view of this holistic perspective regarding supply chain sustainability, a comprehensive definition of the construct is important. Ref. [16] defined sustainable supply chain management (SSCM) as "the creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the shortand long-term." Furthermore, supply chain sustainability also entails good governance practices throughout the life cycle of products and services. SSCM and SCS, therefore, complement each other. The overarching context of these definitions also facilitates the incorporation of SCV to establish an integrative pathway towards sustainable supply chain visibility. Sustainable supply chain visibility extends traditional supply chain visibility to encompass economic, environmental, and social objectives of the supply chain [11]. An integrated approach is critical to building a conceptual platform that can examine the effectiveness of blockchain technology in a supply chain context.

2.3. Blockchain Technology

Mechanisms and technological approaches such as radio frequency identification (RFID), serialization, bar codes, and e-pedigree that enable visibility across the supply chain, have experienced certain limitations. The main reason is due to their centralized operational approach. Consequently, critical features of security and privacy may be compromised using a centralized approach. Security and privacy are critical for high levels of trust. In a system where security and privacy constitute primary objectives, trust remains the common denominator among constituent components. BCT in its decentralized operational approach possesses enormous potential to resolve issues of trust within supply chain networks. Nonetheless, most studies that explored BCT adoption are either conceptual or address the issue from an individual perspective and lack empirical evidence [17]. Even though supply chain sustainability is at the heart of this research, an initial review of the characteristics and features of BCT is necessary.

High-level definitions of blockchain vary in the literature. It is described as a network by some, but meanwhile others have given it a database delineation. Satoshi Nakamoto (name used by pseudonymous person or persons) conceptualized blockchain in 2008. Its first application was bitcoin, which later gave rise to a variety of cryptocurrencies. There is no doubt that the financial domain has profited the most from this innovation, but that does not restrict further usages, especially in supply chain management. Blockchain is a distributed ledger or database running simultaneously on many (possibly millions of) nodes that can be distributed geographically and across many organizations or individuals [18]. Based on the described framework, data shares on a peer-to-peer network in the distributed ledger. "The network members (nodes) communicate and validate the data following a predefined protocol without a central authority" [19]. In contrast to the fact that the centralized approach presents issues of trust in existing technologies, BCT is very secure. Distributed ledgers can be either decentralized, giving equal rights to all users, or centralized, providing specific users with special rights [19]. These structures allow for three sub-categories of networks; that is, public, private, and federated blockchains. Whereas anyone (node) can anonymously join and be allowed to transact without permission in a public blockchain, both private and federated blockchains are permissioned blockchains [11]. However, whatever approach blockchain implementation adopts, transparency among nodes in the network cannot be compromised. The potential of BCT is not limited to its decentralized orientation, but is further amplified by auxiliary features including, distributed ledgers, immutability, consensus, and smart contracts. Recent advancements such as the internet of things (IOT) and artificial intelligence (AI) constitute leading technologies to complement BCT for SCM. Ref. [20] demonstrated that combining blockchain technology with IoT and smart contract provides a seamless supply chain automation environment, which can achieve cryptographic verifiability and significant cost and time savings.

2.3.1. Distributed Ledgers

Blockchain consists of nodes, which represent participating network members. Distributed ledgers use these nodes to capture, share, and synchronize transactions across the network. For this to achieve an instance (cryptographic hash) of all preceding transactions, it replicates into subsequent nodes that eventually append to the chain. It is worth noting that the distributed ledger feature is only adopted in blockchain technology, and therefore, not all distributed ledgers are blockchains. This feature sets the stage for a decentralized framework as earlier described. Decentralization eliminates the centralized approach and addresses information inequalities by allowing for direct transaction among users [4]. Transparency and efficiency are the benefits of such infrastructure. In promoting transparency, all participants in the network have control of information and transactions. Efficiency is also achieved through a synchronized network, which minimizes transaction time. A distributed network infrastructure is reproducible within the context of a supply chain, regardless of how extensive the supply chain may seem. The quest for measures of sustainability in a complex supply chain depends to a great extent on transparency and accessibility of information within the network.

2.3.2. Immutability

Immutability is an important characteristic of blockchain technology. A system free of data integrity issues is ideal, especially in a supply chain, where downstream partners are frequently at the mercy of their upstream peers in the authenticity of material composition, provenance and much more. This is a critical aspect of supply chain sustainability. It is imperative to trust incoming data, and a good way of gaining that trust is by making sure it is original. Any alteration to data in the blockchain follows another block appendage to the chain that is transparent to all participants. Once a transaction records in the system with a validated signature given to the users, it remains unchanged [13]. A blockchain can become vulnerable if it is subject to control by one entity in the network. This could happen if that entity owns more than 50% of the nodes in the blockchain network. On the other hand, the immutability feature can minimize the human intervention of records [4], and prevent vulnerabilities seen in manual and more centralized systems where data changes can either be erroneous or inappropriately manipulated. Nonetheless, immutability is feasible only if nodes in the network distribute fairly.

2.3.3. Consensus

Security is paramount in a network. The consensus feature of BCT can guarantee data security. It is achievable through a consensus from all users in the network to enable a transaction within the blockchain. Consensus is an agreement made among participants, which dictates the process in which data gets written and updated in a blockchain. The consensus algorithm is defined by a set of rules and procedures to maintain the coherency between multiple participating nodes which is based on a notion that a majority (or, in some cases, all) of network validators should agree on the state of the ledger [21]. In blockchain technology, mechanisms are deployed to ensure that the rules, procedures, and agents that generate changes in the blockchain are trustworthy. Typical examples are proof of work, proof of authority, and proof of importance. These are key features that support data security and have the potential to help resolve issues of trust within supply chain partners following a sustainability inquiry.

2.3.4. Smart Contracts

Smart contracts are programmable computer codes that execute within a blockchain. Nick Szabo, a cryptographer, generated the idea of smart contracts in the early 1990's. According to [22], a smart contract is a computerized transaction protocol that executes the terms of a contract. Smart contracts complement BCT by eliminating third parties that function as intermediaries in a traditional contract arrangement. Smart contracts differ from traditional contracts in the sense that they are automatic and deterministic. A third party acting as an intermediate agent in a contract arrangement may fail the essential component of trust required in the transaction, and the decision-making process may be subject to human errors and untimeliness. Smart contracts can be deployed on blockchain platforms in terms of scripts and stored with specific addresses for functional calls like those performed in other programmable computer languages [23]. Regulated conditions and agreements can be coded in smart contracts to avoid fraud, theft, or other managerial risks [24]. This can be beneficial in eliminating counterfeit parts in the supply pipeline and ensuring the integrity of components, raw materials, and finished goods in a supply chain sustainability initiative. Although smart contracts have always been intriguing from a theoretical perspective, at the time of their conceptualization, economic limitations and insufficient communications infrastructure often imposed obstacles to adopting smart protocols in real-world applications [25].

3. Methodology

An appropriate methodology is critical in establishing a platform to analyse research undertakings. Methodology is the study of the means of attaining knowledge of the world, rather than the techniques of research practices themselves [26]. This study adopts the content analysis approach to provide answers to the research questions. Content analysis is a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use [27]. While a small number of recent research articles in BCT for SCM have employed the content analysis method, their overall research trajectories were carefully guided by their unique objectives. Refs [28–30] applied a systematic literature review to investigate the potential of BCT in operations and supply chain management. However, this research endeavor focuses on supply chain sustainability rather than generic improvement initiatives. To answer the research questions through a systematic literature review as prescribed by the method, the study considers the context of supply chain visibility, supply chain sustainability, and BCT as operationally defined. Therefore, it is imperative to apply guidelines for inference (based on existing theories, previous research, or experience) and strict procedural (coding) rules to move from unstructured text to answers to the research questions [31]. The available literature for BCT is not as expansive as that of supply chain management. Furthermore, blockchain utilization in general is still in its infancy, especially in areas of supply chain sustainability. This research does not limit its scope to specific supply chains based on industry but maintains its delimitation to aspects of visibility and sustainability. To the extent that this research area has fairly addressed, there is an apparent lack of empirical investigations. Since content analysis is in the intersection of qualitative and quantitative research methodologies, related studies of this nature will eventually lead to future empirical findings. The preliminary steps involved in conducting content analysis research are:

(1) Establishing search criteria and procedures for articles;
(2) Classification of articles.

These steps are applicable in this research. A systematic review of recent literature will allow for proper data collection, analysis, and synthesis of related papers that address the specificities of this research. Online databases including IEEE, Web of Science, and Scopus served as platforms in the search for academic literature. These sources are reputable, especially in topics regarding technology, supply chain management, and sustainability. Academic articles and conference papers were primary targets, and there were instances of cross-referencing. High quality publications were desirable and could be best derived through peer-reviewed articles. However, the contemporaneity of the phenomenon made it necessary to explore other secondary sources for the purpose of general or novel information on the subject matter. The search incorporated only articles published from 2016 to February 2022. Publications covering both SCM and BCT first appeared together in 2016 on the Scopus database [7]. To avoid extraneousness, the main search key words used were supply chain sustainability, supply chain visibility, traceability, tracking, and blockchain technology. The initial search yielded, in total 48 results; Figure 1 below shows the distribution of the articles.

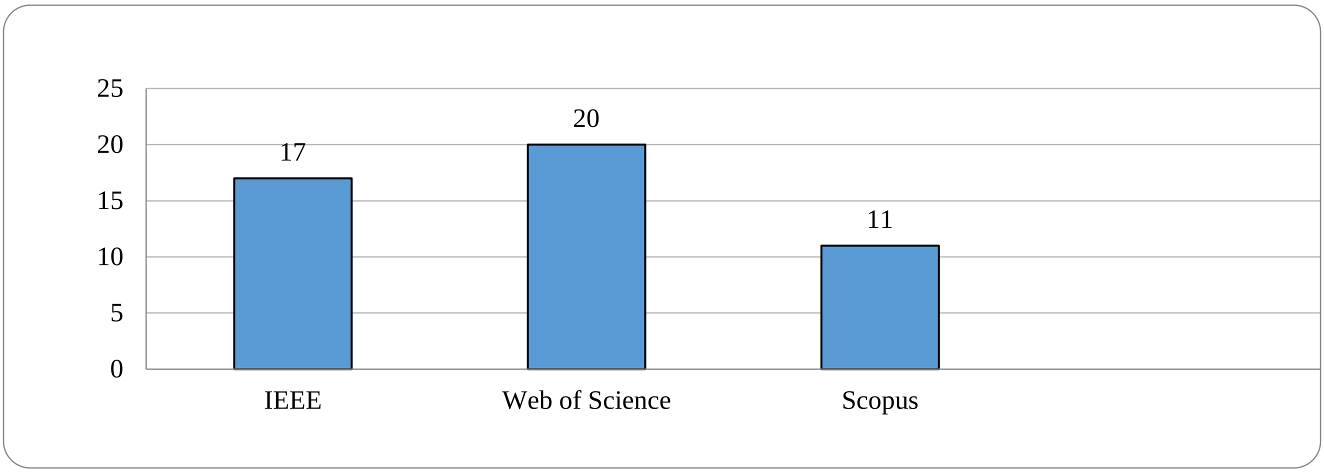

Figure 1. Initial search results of articles by source.

A thorough review process was used to scrutinize the initial 48 articles. To reduce ambiguity, the inclusion criteria restricted the search to only papers that potentially addressed either one or more of the three research questions as restated below.

RQ1 What is the extent to which research has been conducted about block chain technology utilization in supply chain sustainability?
RQ2 What are the currently-known benefits of block chain technology to supply chain visibility?
RQ3 What are the current challenges faced by block chain technology in supply chain provenance?

The second phase screened abstracts, introductions, and conclusions of these articles. This process yielded 30 relevant articles. In the third phase, all articles were reviewed in full for final inclusion. As a result, 21 useful articles were selected to undergo content analysis (the fourth phase). Figure 2 and Table 1 below show the distribution and titles of the selected articles.

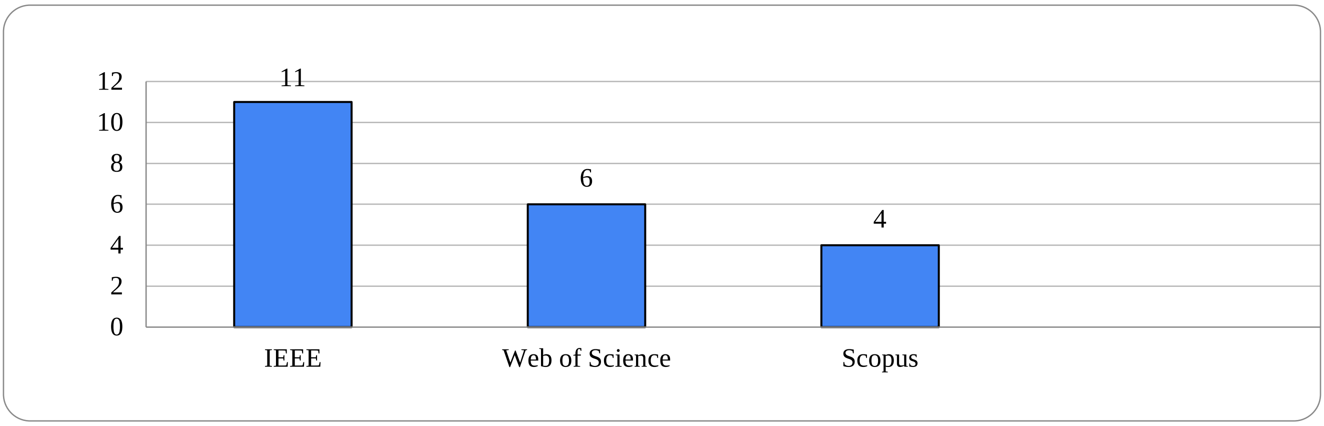

Figure 2. Final results for articles by source.

Table 1. List of selected articles.

Sr. No.	Article Name	IEEE	Web of Science	Scopus
1	A_Meta_Model_for_a_Blockchain-based_Supply_Chain_Traceability	☑		
2	An analytical approach for evaluating the impact of blockchain technology.pdf		☑	
3	An_agri-food_supply_chain_traceability_system_for_China_based_on_RFID_amp_blockchain_technology.pdf	☑		
4	Blockchain_anchored_supply_chain_automation.pdf	☑		

Table 1. *Cont.*

Sr. No.	Article Name	IEEE	Web of Science	Scopus
5	Blockchain_in_Logistics_and_Supply_Chain_A_Lean_Approach_for_Designing_Real-World_Use_Cases.pdf	☑		
6	Context-Aware Blockchain-Based Sustainable Supply Chain.pdf		☑	
7	Digital extraction Blockchain traceability in mineral supply chains.pdf		☑	
8	Digitalizing the Closing-of-the-Loop for Supply Chains.pdf			☑
9	Enabling_Privacy_and_Traceability_in_Supply_Chains_using_Blockchain_and_Zero_Knowledge_Proofs.pdf	☑		
10	Enhancing_Traceability_in_Pharmaceutical_Supply_Chain_using_Internet_of_Things_IoT_and_Blockchain.pdf	☑		
11	Ensure_Traceability_in_European_Food_Supply_Chain_by_Using_a_Blockchain_System.pdf	☑		
12	Inventory_Visibility_Scenario_to_Reduce_Safety_Stock_in_Supply_Chain_Network_Using_Blockchain_Hyperledger_Composer.pdf	☑		
13	Molina2019_Chapter_UsingBlockchainForTraceability.pdf		☑	
14	Potentials of Blockchain Technologies in Supply Chain.pdf			☑
15	Research on logistics supply chain of iron and steel enterprises based.pdf			☑
16	Research_on_data_storage_model_of_household_electrical_appliances_supply_chain_traceability_system_based_on_blockchain.pdf	☑		
17	Secure_Identification_Traceability_and_Real-Time_Tracking_of_Agricultural_Food_Supply_During_Transportation_Using_Internet_of_Things.pdf	☑		
18	Sustainable_B2B_E-Commerce_and.pdf		☑	
19	The power of a blockchain-based supply chain.pdf			☑
20	Toward_Blockchain-Enabled_Supp.pdf		☑	
21	When_Blockchain_Meets_Supply_Chain_A_Systematic_Literature_Review_on_Current_Development_and_Potential_Applications.pdf	☑		

4. Classification

To facilitate examination, articles were classified along three critical dimensions. The three categories are:

(1) Year of article publication;
(2) Relevance of article to the research constructs;
(3) Relevance of article to the research questions

Descriptive analysis provides the first insight into the papers [4]. Inferences derived from such preliminary data analysis help in guiding and supporting the research findings.

4.1. Year of Article Publication

The recency of BCT-related research warranted an inquiry on the frequency and progression of studies in this niche. The inclusion criteria during the search allowed for the review of articles published exclusively between 2016 and 2022, which made it easier to identify chronological trends in the progression of research. Figure 3 and Table 2 show the distribution and identify the year in which articles addressing this subject were published.

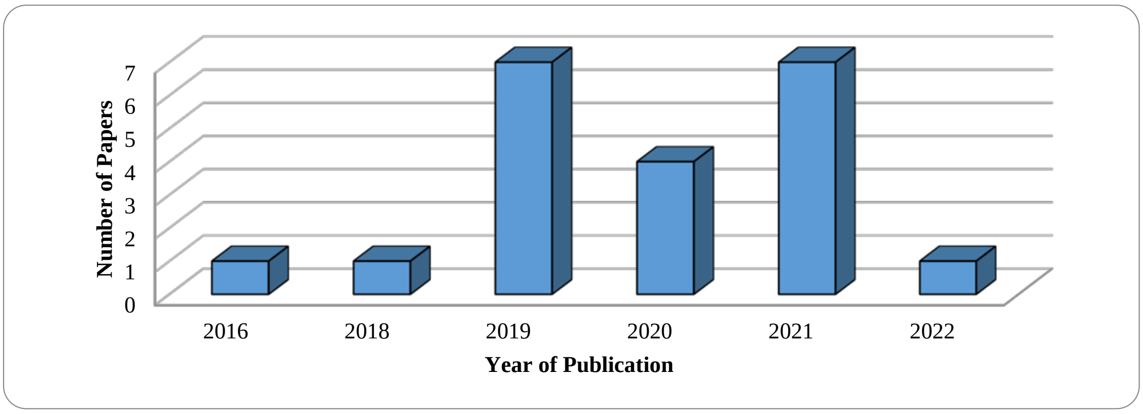

Figure 3. Result for year of article publication.

Table 2. Distribution of selected articles according to year of publication.

Sr. No.	Paper Name	2016	2018	2019	2020	2021	2022
1	A_Meta_Model_for_a_Blockchain-based_Supply_Chain_Traceability			☑			
2	An analytical approach for evaluating the impact of blockchain technology.pdf						☑
3	An_agri-food_supply_chain_traceability_system_for_China_based_on_RFID_amp_blockchain_technology.pdf	☑					
4	Blockchain_anchored_supply_chain_automation.pdf			☑			
5	Blockchain_in_Logistics_and_Supply_Chain_A_Lean_Approach_for_Designing_Real-World_Use_Cases.pdf		☑				
6	Context-Aware Blockchain-Based Sustainable Supply Chain.pdf					☑	
7	Digital extraction Blockchain traceability in mineral supply chains.pdf					☑	
8	Digitalizing the Closing-of-the-Loop for Supply Chains.pdf					☑	
9	Enabling_Privacy_and_Traceability_in_Supply_Chains_using_Blockchain_and_Zero_Knowledge_Proofs.pdf				☑		
10	Enhancing_Traceability_in_Pharmaceutical_Supply_Chain_using_Internet_of_Things_IoT_and_Blockchain.pdf			☑			
11	Ensure_Traceability_in_European_Food_Supply_Chain_by_Using_a_Blockchain_System.pdf			☑			
12	Inventory_Visibility_Scenario_to_Reduce_Safety_Stock_in_Supply_Chain_Network_Using_Blockchai _Hyperledger_Composer.pdf					☑	
13	Molina2019_Chapter_UsingBlockchainForTraceability.pdf			☑			
14	Potentials of Blockchain Technologies in Supply Chain.pdf				☑		
15	Research on logistics supply chain of iron and steel enterprises based.pdf			☑			
16	Research_on_data_storage_model_of_household_electrical_appliances_supply_chain_traceability_system _based_on_blockchain.pdf					☑	
17	Secure_Identification_Traceability_and_Real-Time_Tracking_of_Agricultural_Food_Supply_During_Transportation_Using_Internet_of_Things.pdf					☑	
18	Sustainable_B2B_E-Commerce_and.pdf				☑		
19	The power of a blockchain-based supply chain.pdf			☑			
20	Toward_Blockchain-Enabled_Supp.pdf					☑	
21	When_Blockchain_Meets_Supply_Chain_A_Systematic_Literature_Review_on_Current_Development_and _Potential_Applications.pdf				☑		

4.2. Relevance of Article to Research Constructs

Another important dimension considered the three main constructs, which are the principal research predicates. Being mindful of the operational definitions of supply chain sustainability, supply chain visibility, and BCT as previously indicated, selected articles were categorized based on their relevance to the research constructs. There was overlap among constructs as well. Table 3 (consolidated table) shows in part the distribution of articles based on linkage with the research constructs.

Table 3. Consolidated distribution based on construct and research question relevance.

Sr. No.	Article Name	SCV	SCS	BCT	RQ1	RQ2	RQ3
1	A_Meta_Model_for_a_Blockchain-based_Supply_Chain_Traceability	☑		☑		☑	☑
2	An analytical approach for evaluating the impact of blockchain technology.pdf		☑	☑	☑		☑
3	An_agrifood_supply_chain_traceability_system_for_China_based_on_RFID_amp_blockchain _technology.pdf	☑		☑		☑	☑
4	Blockchain_anchored_supply_chain_automation.pdf	☑		☑		☑	☑
5	Blockchain_in_Logistics_and_Supply_Chain_A_Lean_Approach_for_Designing_Real-World_Use_Cases.pdf	☑	☑	☑	☑	☑	☑
6	Context-Aware Blockchain-Based Sustainable Supply Chain.pdf	☑	☑	☑	☑	☑	☑
7	Digital extraction Blockchain traceability in mineral supply chains.pdf		☑	☑			☑
8	Digitalizing the Closing-of-the-Loop for Supply Chains.pdf		☑	☑	☑		
9	Enabling_Privacy_and_Traceability_in_Supply_Chains_using_Blockchain_and_Zero _Knowledge_Proofs.pdf	☑		☑		☑	
10	Enhancing_Traceability_in_Pharmaceutical_Supply_Chain_using_Internet_of_Things_IoT_and _Blockchain.pdf			☑	☑	☑	
11	Ensure_Traceability_in_European_Food_Supply_Chain_by_Using_a_Blockchain_System.pdf	☑		☑		☑	☑
12	Inventory_Visibility_Scenario_to_Reduce_Safety_Stock_in_Supply_Chain_Network_Using _Blockchain_Hyperledger_Composer.pdf	☑		☑		☑	☑
13	Molina2019_Chapter_UsingBlockchainForTraceability.pdf	☑		☑		☑	

Table 3. *Cont.*

Sr. No.	Article Name	SCV	SCS	BCT	RQ1	RQ2	RQ3
14	Potentials of Blockchain Technologies in Supply Chain.pdf			☑			☑
15	Research on logistics supply chain of iron and steel enterprises based.pdf			☑	☑	☑	
16	Research_on_data_storage_model_of_household_electrical_appliances_supply_chain _traceability_system_based_on_blockchain.pdf	☑		☑		☑	☑
17	Secure_Identification_Traceability_and_Real-Time_Tracking_of_Agricultural_Food_Supply_During_Transportation_Using_Internet_of _Things.pdf	☑		☑		☑	☑
18	Sustainable_B2B_E-Commerce_and.pdf	☑	☑	☑	☑	☑	☑
19	The power of a blockchain-based supply chain.pdf	☑		☑		☑	☑
20	Toward_Blockchain-Enabled_Supp.pdf	☑		☑		☑	☑
21	When_Blockchain_Meets_Supply_Chain_A_Systematic_Literature_Review_on_Curren _Development_and_Potential_Applications.pdf	☑	☑	☑	☑	☑	☑

4.3. Relevance of Article to Research Questions

To answer the research questions in a holistic fashion, a systematic approach ensued. A stringent review of each article allowed for further classification based on research questions. The rationale for this classification was primarily based on the objectives and findings of the article. All twenty-one articles meeting the criteria could address two, or all three, research questions. Table 3 (consolidated table) shows in part the distribution of articles based on the relevance to the research questions.

5. Conceptual Model

Upon review of prevailing literature in BCT and SCS, a better understanding of the technological, economical, and socio-political potentials as well as challenges of blockchain leverage emerges. Irrespective of the recency of the subject, ref. [32] argued that major enterprises and organizations are actively promoting the innovation and application of blockchain in supply chain, which has attracted significant attention from academia and industry [32]. As evident in the literature review, this observation is congruent with the study's a priori position. This research proposes a conceptual model for blockchain-enabled sustainable supply chain visibility based on the three main research constructs.

The conceptual model identifies characteristics inherent to BCT that support supply chain visibility within the context of provenance. It is based on the premise that supply chain sustainability is achieved through enhanced visibility driven by blockchain technology. Figure 4 shows the proposed conceptual model upon which the research findings are reinforced.

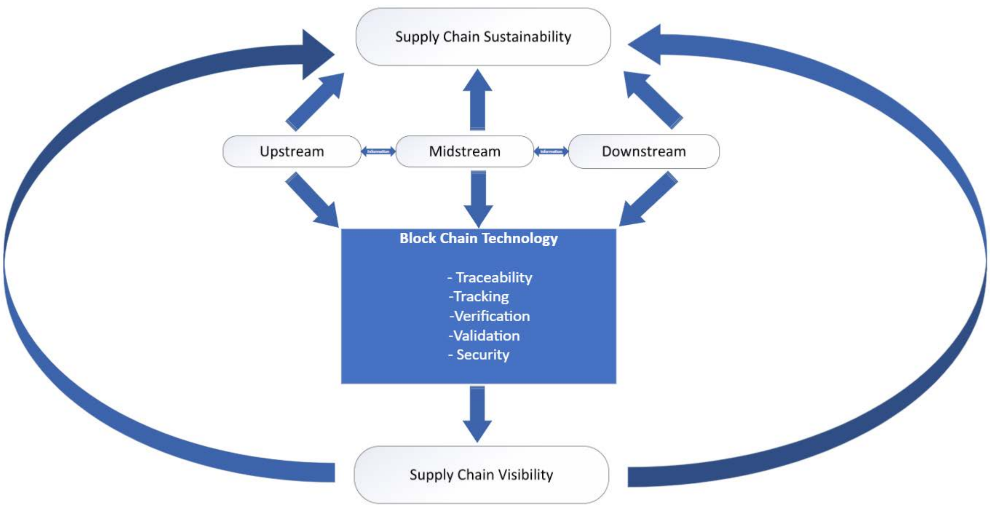

Figure 4. A conceptual model for blockchain-enabled sustainable supply chain visibility.

6. Results and Discussions

The proposed conceptual model for blockchain-enabled sustainable supply chain visibility establishes a pathway for easy interpretation of the twenty-one articles critically reviewed to answer questions raised by this research. This section discusses the research findings by addressing the questions and providing evidence of benefits and challenges of BCT to supply chain visibility and supply chain provenance, respectively.

6.1. Blockchain Research in Supply Chain Sustainability

RQ1 What is the extent to which research has been conducted about block chain technology utilization in supply chain sustainability?

According to the data analyses performed using sample articles collected, RQ1 can be addressed on two fronts. The year of article publication and the relevance of articles on research questions do provide evidence of the extent to which research has been conducted in this niche. Figure 3 shows the distribution of the years in which articles addressing this subject were published. The time trend indicates that BCT is gaining increasing attention and interest in supply chain sustainability. The recency of the phenomenon necessitated data collection only within a restricted period between 2016 to March of 2022. The time trend clearly depicts a progression of research interest based on the number of publications. However, there is an inconsistency as seen in the chart, which indicates a decrease in the number of publications in 2020. This could be explained by several factors, including the unprecedented COVID 19 pandemic and a limited leverage of publication databases. Furthermore, Table 3 shows in part the distribution of articles based on the relevance to the research questions. RQ1 is clearly linked with eight research articles that highlight continued interest in this research area. In a recent study that proposed an analytical approach to assessing the impact of BCT on sustainable supply chain performance, ref. [33] compared their conceptual model to those of 10 recent studies, which displayed models in assessing supply chain performance and sustainability in mining supply chains. The capabilities of BCT for efficient supply chain management have become more pervasive in recent years [33]. Prospects of studies seeking trajectories to uncover capabilities of BCT in traceability across integrated functional areas have increased significantly. Ref. [34] for instance, aspires to extend the scope of an investigation of BCT in the iron and steel enterprises beyond the logistic chain. Integrating the financial chain, production chain and supply chain will provide better data resource leverage and make capital flow and information flow more secure and reliable [34]. Blockchain, with its unique characteristics, has received growing attention from engineers, researchers, and practitioners in the last decade [24]. There is no doubt that this research area will enjoy continued growth in both academic and practical application sectors.

6.2. Benefits of BCT to Supply Chain Visibility

RQ2 What are the currently-known benefits of block chain technology to supply chain visibility?

Recent literature on BCT indicates significant benefits from a supply chain visibility point of view. This is consistent with results of the analyses, where over 85% of the reviewed articles were relevant to RQ2. Moreover, irrespective of the fact that the typical benefits of BCT have mostly been conceptually demonstrated, their impact can also be corroborated by a few recent successful applications. One such success is exemplified by the blockchain-based supply chain solution developed by SIMBA Chain in collaboration with the University of Notre Dame for Toks (a fast-food/casual restaurant chain based in Mexico). The application has made it possible for Toks to extensively track coffee bean distribution throughout its value chain, and eliminate several intermediaries in the supply chain, thereby increasing the average farmer's income by 700%. This case not only substantiates the features of BCT as earlier discussed, but clearly demonstrates the implications of both economic and social dimensions of sustainability. Furthermore, implementation of blockchain-based traceability solutions has succeeded in sectors such as cobalt mining [35]. This is because of the production of lithium-ion batteries, which necessitates suppliers abide by legal and responsible sourcing practices [36]. The food supply chain safety arena also has presented advancements in the leverage of blockchain technology. Ref. [37] accentuated two blockchain projects launched by Walmart in partnership with IBM to streamline pork imports from China and mango imports from America. IBM developed a Food Trust system based on Hyperledger Fabric for improving food supply chain management [38]. The [39] solution to enable agri-food supply chain traceability in China further exemplifies a scenario whereby BCT complements radio frequency identification (RFID) technology to enhance supply chain visibility. Ambrosus and Modum, two Swiss startups, have developed a system that merges internet-of-things (IoT), BCT, and real-time sensors to trace and transmit a products' information during the whole of the manufacturing process [40]. They share a similar objective to optimize supply chain visibility and quality assurance in the food and pharmaceutical sectors. While the Ambrosus network uses tags, tracers, and sensors to track products throughout their lifecycles [40] in the food and pharmaceutical supply chains, the Modum network focuses on monitoring shipments to ensure safe delivery of products specifically in the pharmaceutical supply chain. In addition to traceability, BCT provides opportunities in supply chain anti-counterfeiting. To better prevent risks and overcome threats with vulnerabilities initiated by centralized architecture, BCT (or other distributed ledger technologies built with decentralized networks) stands out as a potential framework to establish a modernized, decentralized, trustworthy, accountable, transparent, and secured supply chain innovation against counterfeiting attacks when compared with those developed based on a centralized architecture [41].

6.3. BCT Challenges in Supply Chain Provenance

RQ3 What are the current challenges faced by block chain technology in supply chain provenance?

Supply chain provenance continues to gain significant importance in sustainable development. Ref. [42] contended that firms establishing product provenance may gain competitive advantage due to increasing skepticism manifested by consumers. Provenance knowledge comes from supply chain transparency in terms of how products were manufactured, stored, and delivered to customers [43]. While the reviewed articles in this research found immense benefits from BCT to supply chain sustainability as indicated in the previous section, several important challenges were also raised. In fact, over 75% of the selected articles were relevant to RQ3. This significant number indicates that challenges of BCT are prevalent in the literature and therefore cannot be overlooked. Evaluating provenance of physical goods, or what we call supply chain provenance, has been more difficult because so many goods are handled in complex, international supply chains where granular tracking of physical characteristics and product whereabouts has not been possible [43]. The advent of IoT and blockchain technologies in recent years has begun to facilitate traceability efforts in supply chains. These technologies, however, remain a work in progress despite some successful deployments, and therefore it is critical to point out impediments that could be improved. By 2022, 80% of blockchain supply chain initiatives will remain at a proof-of-concept or pilot stage [44]. The divergent and contested positions articulated by various actors in both academia and practice over blockchain capabilities is a potential drawback. According to [44], a lack of consensus on blockchain capabilities, irrespective of discussions across the board on potential and hype, presents a significant barrier to adoption. Ref. [45] developed a conceptual model which applied six core influencing factors and four moderating effects to interrogate the potential of BCT in supply chain management. Among these factors and effects, control, scalability, knowledge, and regulation appear to be key challenges to supply chain provenance. Controllability is dependent on external and internal decisions, which makes it even more difficult to regulate [45]. The issue of scalability is addressed from many fronts in the blockchain literature. Practically, it is impossible to maximize scalability alongside security and privacy, which are core features of blockchain technology. Interestingly, the co-founder of Ethereum (i.e., one of the most widely used cryptocurrencies, along with Bitcoin) coined the term "scalability trilemma" to indicate the difficulty of combining decentralization, scalability, and security [46]. While a blockchain-enabled supply chain network with a large amount of participates (nodes) can increase the security dimension, it then requires a longer time for the nodes to reach a consensus. Moreover, to achieve the maximum potential of blockchain in the supply chain, all participants within the supply chain must share the same level of knowledge regarding the technology, its functions, and purpose [45]. Ref [7] buttresses this argument from a supply chain visibility point of view, by purporting that supply chain participants need a unified view of production, shipment, delivery, and sales data, while still verifying transactions independently and privately.

7. Conclusions

The growing interest to seek sustainably manufactured consumer products downstream has triggered the exploration of innovative solutions, including blockchain technology. Complexities in the contemporary business environment, including multi-echelon supply chain networks, are the main drivers of this paradigm shift. This research presents an in-depth review of leveraging BCT in supply chain sustainability. A conceptual model for sustainable supply chain visibility established the means to facilitate responses to the main inquiries. A preponderance of the articles reviewed echoed the promising capabilities of BCT to resolve issues of supply chain provenance. As observed, there is a continued growth in this research area in both academe and practice. Compared with existing technological mechanisms used to enhance visibility in the supply chain such as the RFID, IOT, epedigree and enterprise systems, BCT stands out in its decentralized ability to provide trust, accountability, transparency, and security. The research explicates these key BCT characteristics by providing some developed applications and case studies, which exemplify successful BCT implementations in supply chain provenance through extensive tracking and tracing within the value chain. The Toks/Simba Chain and Walmart/IBM initiatives to enhance provenance are a few examples. Nonetheless, the research uncovered critical challenges of BCT, especially in sustainable supply chain visibility. These challenges include control, scalability, regulation, and knowledge. While most of these limitations are technically driven, it is imperative for participants within the supply chain to share the same level of knowledge regarding the objective and functionality of the technology. Besides, it is worthwhile considering other major bottlenecks in blockchain adoption such as culture, government policies, and criminal activities. All these challenges of BCT exist largely because of the novelty of the technology. Meanwhile, the apparent growth in this research area is indicative of a potential to unravel solutions to these roadblocks.

This study contributes to the collective research effort in supply chain sustainability improvements using technology. Specifically, it bridges the gap and comprehensively seeks to investigate the potential of BCT in addressing provenance issues of raw materials, components, and finished goods throughout the value chain. It also looks at the fundamental aspects of blockchain and potential impacts, which will be useful in guiding researchers in this niche, and provides some insights for practitioners, and subject matter experts in assessing BCT for supply chain sustainability initiatives. The analyses in this work will help to lay a solid foundation for future research and suggest new research trajectories.

The study encountered some limitations. The articles extracted from the search effort were reduced to 21 useful articles for content analyses. Even though this is a relatively small number which may not be sufficient to avoid some research bias, it should be noted that very limited research has addressed the subject of supply chain sustainability and BCT combined.

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