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Review

Blockchain Changing the Outlook of the Sustainable Food Supply Chain to Achieve Net Zero?

Aditi S. Saha [1,*], Rakesh D. Raut [1], Vinay Surendra Yadav [2] and Abhijit Majumdar [3]

[1] Department of Operations and Supply Chain Management, National Institute of Industrial Engineering (NITIE), Mumbai 400087, Maharashtra, India
[2] Operations and Quantitative Technique, Indian Institute of Management, Shillong 793018, Meghalaya, India
[3] Department of Textile and Fibre Engineering, Indian Institute of Technology Delhi, New Delhi 110016, India
* Correspondence: aditi.saha.2020@nitie.ac.in

Abstract: The food supply chain (FSC), being a complex network, faces major issues such as traceability, food security, safety and sustainability. Blockchain technology (BLCT) is regarded as an innovative technology that can transform FSC by means of its traceable, irrevocable, tamperproof network. BLCT being a new technology, little work has been carried out on the FSC domain. The purpose of the study is to examine the most recent trends, benefits, challenges, and application of BLCT in the FSC and explore the comprehensive adoption and application of BLCT, stating how it helps to achieve a triple bottom line (TBL) and net zero in the supply chain. The methodology used in this article is a systematic literature review (SLR) comprising 55 papers spanning the years 2018 to 2022. The findings of the study state that BLCT helps to achieve food safety, security, and traceability and increases the performance of the FSC. It also contributes to achieving the TBL of sustainability which can further help to achieve net zero. Based on this work's insight and observations, practitioners and academics can better understand how companies can implement BLCT and achieve TBL benefits in the FSC, which could eventually provide a path to achieving net zero.

Keywords: sustainability; blockchain; food supply chain; food safety; food security; traceability; net zero

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1. Introduction

The "World Commission on Environment and Development" defines sustainable development as "filling the demands of the present without affecting future generations' ability to fulfil their own needs" [1,2]. The 2030 Agenda for Sustainable Development Goal (SDG) globally identifies food and agriculture as key sustainable development sectors. In this context, the food supply chain (FSC) is inextricably linked to sustainability since output must be raised to satisfy the demands for the future, wherein rising competition for more limited resources is inevitable. According to the United Nations Environment Programme (UNEP) research, nearly one-third of the food produced for human consumption is wasted each year, amounting to more than 1.3 billion tons globally. More than 40% of losses in developing countries occur during the post-harvesting and processing stages, while more than 40% occur at the retail and consumer levels in developed countries (source). The study states that the lack of coordination and transparency among the supply chain partners leads to increased losses in the network.

Furthermore, large amounts of food are wasted at retail because of quality standards that emphasize appearance. The sustainable development goal (SDG) 12 focuses on responsible consumption and production by reducing global food waste. This includes the reduction of losses at retail and consumer levels and along the entire food supply chain. Thus, providing food while causing little or no damage to the environment and nature is a significant concern for agricultural scientists.

FSC manufactures are required to ensure timely delivery of high-quality products at low prices and low operating costs, to meet customer expectations. Many companies are also outsourcing parts of their supply chain activities to other companies and/or locating their manufacturing and distribution hubs in low-cost areas, thus, complicating supply chains even further. Due to the increasing complex supply chains, pollution levels have grown, resulting in global warming. Global greenhouse gas emissions from agricultural production currently account for 11% of the global total and have increased 14% since 2000, according to the World Resources Institute. The Intergovernmental Panel on Climate Change (IPCC), 2022 [3] report warns that increasing emissions will drastically affect the globe. It is imperative to minimize the contributing factors to greenhouse gas emissions to minimize the effects of climate change and air pollution [4]. Net zero is the concept which suggest that the carbon dioxide and the greenhouse gas level in the air should be close to zero [5]. According to [6], significant technical advancements can minimize CO_2 emissions in the production and supply chain process.

Traditional FSCs are distinguished by strong vertical integration and coordination among supply chain partners to increase efficiency and reduce emissions, such as by minimizing transaction, operational, and marketing costs, and meeting consumer demands for food quality, and safety [7]. In light of the growing concern over sustainability, food safety, provenance, and contamination hazards, it is imperative to develop an effective traceability system that can track a food product's provenance and compile all essential data about its movement transparently and securely [8]. In the study of [9], the authors states that inculcating sustainability in supply chains is crucial to increasing economic growth and accessibility. Achieving sustainability further leads to achieving net zero in FSC, which refers to reducing greenhouse gas emissions to near zero. The concept of net zero focuses on maintaining an ecological balance between producing greenhouse gas emissions and removing these gases from the atmosphere [5,10]. Manufacturers are encouraged to achieve sustainability, reduce carbon emissions, and reduce climate change by implementing net-zero concepts [11]. Thus, blockchain technology can be adapted to inculcate net zero and sustainability in FSC.

As part of its sustainability management strategy, the FSC needs to improve tracking and authenticating information for identifying and addressing contamination sources [12,13]. Blockchain technology (BLCT), a decentralized and immutable technology, presents a pragmatic solution, ensuring traceability in complex food supply ecosystems and eliminating the need for a reliable centralized authority [14]. Blockchains are represented by blocks and validated by cryptography. These blocks contain a timestamp and record the previous block's hash value. These hash values are unique and tamperproof, which helps to prevent fraudulence and provides transparency in the chain [15]. Through the decentralization of BLCT, SC members can reduce their operating time and costs, improve quality and boost efficiency [13,16].

Furthermore, it facilitates the creation of a transparent supply chain, which reduces the chances of fraud, product recalls, and product loss [17]. Thus, BLCT helps to achieve sustainability in FSC by tracing the information on product origin, shelf life, lot details, quality details, transport, and storage monitoring [13,18]. In addition to improving sustainability, this technology is also energy efficient [19,20], and researchers are trying to increase the efficiency by changing the consensus algorithm from proof of work (PoW) to proof of stake (PoS) as it consumes less energy [21]. BLCT is also used to ensure the transmission of real-time, accurate information among the entities in a supply chain, such as transparency, traceability, security, and irreversibility.

According to [22], identifying accurate and relevant sustainability indicators may help consumers in solving challenges with product sourcing and distribution. Furthermore, FSCs are a primary priority, with blockchain committing to better certifications and sustainability standards, promoting organic food and assuring high-quality food product life cycles. Three pillars (environmental, economic, and social) of sustainability, also called the triple bottom line (TBL), have also been revealed to be strongly linked to BLCT [23,24]. By minimizing malpractices, technology can contribute to human rights compliance and safer work practices and add to social sustainability. Implementation of BLCT in FSCs also helps achieve environmental sustainability, improving supply chain performance [25] by reducing carbon emissions, paperwork, wastage, and physical product transportation, further lowering global pollution levels [26]. The authors of [27,28] state that blockchain is a promising technology that will change the future economy dramatically and may be adopted as a wide-ranging approach to achieve high levels of transparency and efficiency while reaching the goal of a more sustainable society while aspiring to achieve net zero along the FSC.

Thus, this study aims to understand the comprehensive implementation of BLCT in a sustainable FSC using a systematic literature review, identifying its benefits, challenges, and application by reviewing the existing knowledge and filling the knowledge gaps. It also focuses on how BLCT helps to provide food safety, security, and traceability in the network. The paper also discusses how BLCT helps to achieve the three pillars of sustainability and net zero in the FSC. In light of the discussion above, we identify the following research questions for this study:

Q1: What are the recent trends, benefits, challenges, and applications of BLCT in the FSC?
Q2: How is BCLT helping to achieve the triple bottom line (TBL) aspects of sustainability in the FSC?
Q3: How will BCLT help to achieve net zero through safety, security, and traceability in the FSC?

The rest of the paper is structured as follows. The methodology of the review process is discussed in Section 2. Section 3 includes a discussion of how blockchain helps to achieve the TBL. Section 4 discusses the application of BLCT. The discussion and conclusion are summarized in Section 5. Managerial insights and future research direction are explored in Sections 6 and 7.

2. Methodology

The purpose of this article is to study the current state of BCLT in sustainable FSCs and how it may help with food traceability, safety, and security, as well as to assess the adoption challenges that come with it. It also discusses the advantages of implementing blockchain, which help to achieve the triple bottom line aspect of the sustainability and net zero. By gathering and summarizing related papers, this review article provides an insightful take on the existing literature. To support this analysis, this paper uses systematic literature review (SLR) technique. We have applied a refinement process adapted and modified from [23], which includes (1) defining the research question (s), (2) searching databases, (3) selecting and screening the relevant research paper, (4) SLR, (5) synthesizing relevant literatures based on attributes identified, categorized, and analysed. Figure 1 diagrammatically explains the steps of the review process.

2.1. Step 1-Database Search

In order to have comprehensive coverage, we performed multiple searches on different databases. Scopus, Web of Science, IEEE, Springer, Science Direct and Ebsco were used for searching relevant articles. Multiple combinations of the following research keywords were used—blockchain, food or agri supply chain, food safety, food security, traceability, performance, sustainability, net zero. In our search for papers related to net zero in agri-food supply chains using BLCT, we found no papers relating to net zero in combination with other keywords, to the best of our knowledge. Table 1 shows the combination of the keywords used for finding the relevant paper. The co-occurrence of the keyword analysis is shown in Figure A1 in Appendix A.

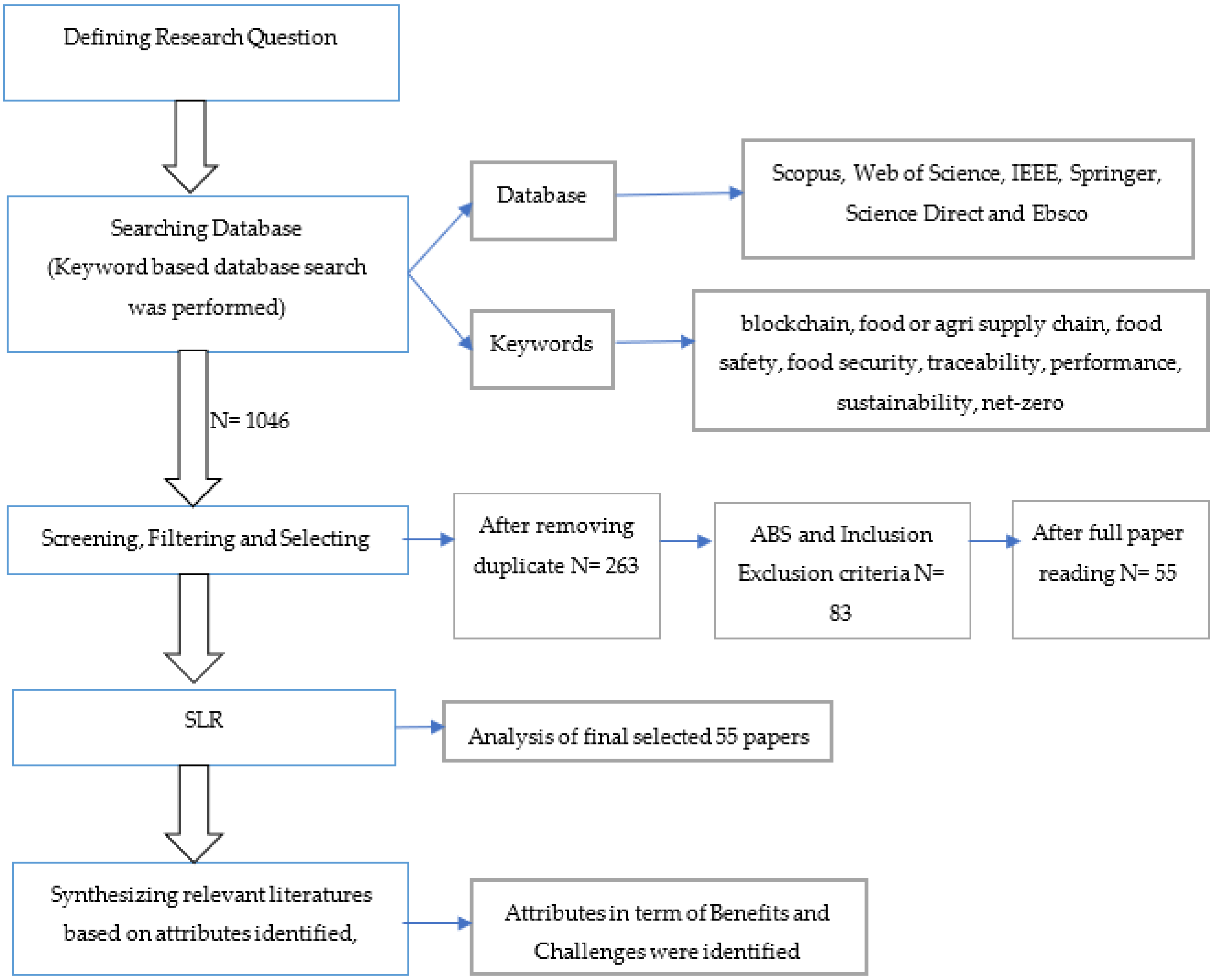

Figure 1. Stages of the literature review process (modified from Li et al., 2021).

Table 1. Combination of keywords used.

Keywords Combination		
"Blockchain", "supply chain", "traceability", "agriculture", "food", "performance", "sustainability"	"Blockchain", "supply chain", "traceability", "agriculture", "food", "security", "safety", "quality", "sustainability"	"Blockchain", "supply chain", "traceability", "agriculture", "food", "performance", "security", "safety", "quality", "sustainability", "net zero"

2.2. *Step 2-Screening and Selection of Research Papers*

After the initial search, duplicate articles across the various databases were removed, and inclusion–exclusion parameters were applied, which are summarized in Table 2. Further, title–abstract keyword criteria were applied where the irrelevant articles were excluded. Papers published from 2018 to May 2022 were included in our study. To increase the authenticity of our research, we included only articles and review papers in the English language; all the other material was excluded from our study. Further, to confirm the relevance of the articles to blockchain application in the FSC, a thorough abstract reading was performed. Finally, 55 relevant papers were finalized for our research based on BLCT and in the FSC domain.

Table 2. Evaluation criteria.

Inclusion	Exclusion	Justification
English language only	Apart from English languages	English is a widely acceptable language across the globe.
Focus on FSC only	Other than FSC	To study the food supply chain specifically
Paper from 2018 to May 2022	Papers before 2018	The research theme is not much developed before 2018
BCLT on agri-food supply chain	Technologies other than BCLT	To study specifically BLCT in FSC as per the research question defined
Article and review papers	Business news, grey articles, conference papers, thesis and whitepapers	To increase the authenticity
Scopus, Web of Science, IEEE, Springer Science Direct and Ebsco	Other databases	High ranked and relevant database

2.3. Step 3-Systematic Literature Review (SLR)

We undertook an SLR [29–31] study to understand the present trend of FSCs in the blockchain. For this review, the R-Bibliometric software tool has been used for analysis. Figure 2 depicts the annual number of research articles published. Although the retrieval period for publications in blockchain-based agriculture is from 2018 to May 2022, papers about blockchain and food initially surfaced in 2018. In the last two years, there has been a significant growth in research on the subject. This upward tendency reflects the newness of blockchain in the food industry and growing interest from researchers, academia, and businesses. Although the number of papers on FSCs using BLCT has increased dramatically since 2020, an article discussing net zero in FSC has not been explored yet.

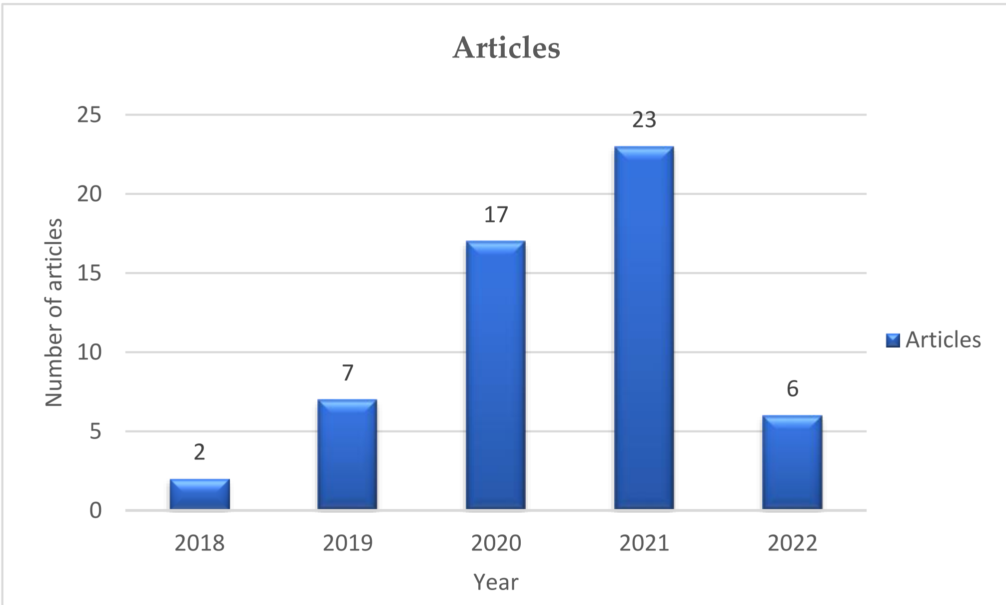

Figure 2. Trend showing the number of publications of FSC.

Figure 3 shows the top 5 relevant sources. Journal of Cleaner Production, IEEE Access, Applied Economic Perspectives and Policy, Sustainability and Food Control are rated among the top 5 sources where most of the articles were published.

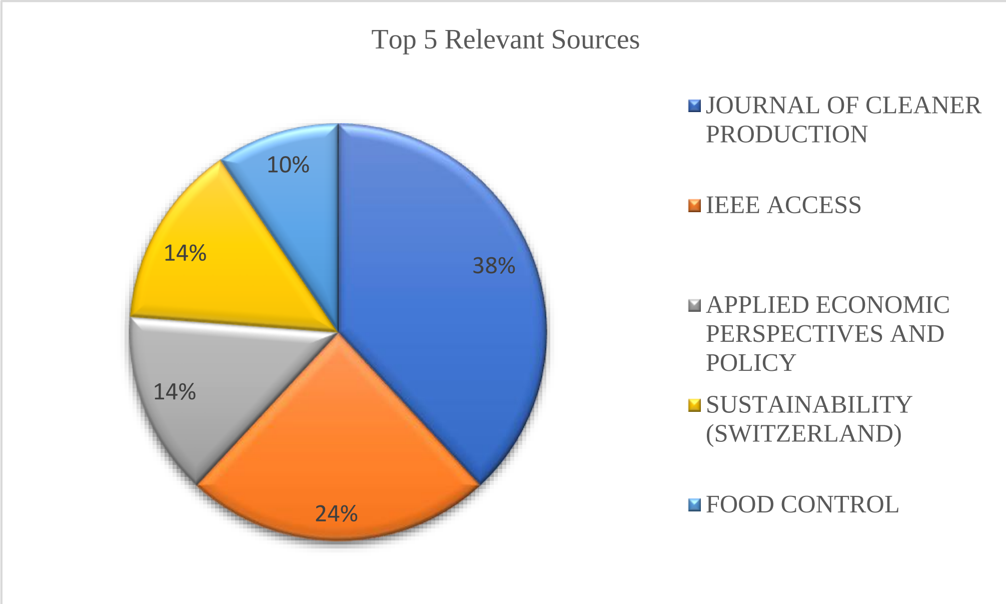

Figure 3. Top 5 relevant sources.

As shown in Table 3, the top 5 relevant sources and authors are ranked by their h-index, g-index, and m-index. "The h-index is an author-level metric that measures both the productivity and citation impact of the publications". G-index was introduced by [32] as an improvement to h- index, it is calculated based on the number of citations received by a researcher's publications. Unlike the h-index, the m-index accounts for years since the first publication and is more relevant for early career researchers. The United Kingdom, China, and USA are the most often mentioned countries, as seen in Figure 4. Clearly, significant work on FSCs with blockchain is being carried out in these advanced economies.

Table 3. Top 5 Source and Author impact factor.

Source	**NP**	**TC**	**h_index**	**g_index**	**m_index**	**PY_start**
IEEE Access	5	121	4	5	1	2019
Journal of Cleaner Production	8	80	3	8	1	2020
Sustainability	3	49	3	3	0.6	2018
Applied Economic Perspectives and Policy	3	11	2	3	1	2021
Food Control	2	67	2	2	0.5	2019
Author	**NP**	**TC**	**h_index**	**g_index**	**m_index**	**PY_start**
Wang X	3	77	2	3	0.667	2020
Hao Z	2	77	2	2	0.400	2018
Mao D	1	48	2	2	0.400	2018
Zhang X	2	41	2	2	0.667	2020
Zhao Z	2	41	2	2	0.667	2020

(NP—Number of publications, TC—Total Citations, PY—Publication Year).

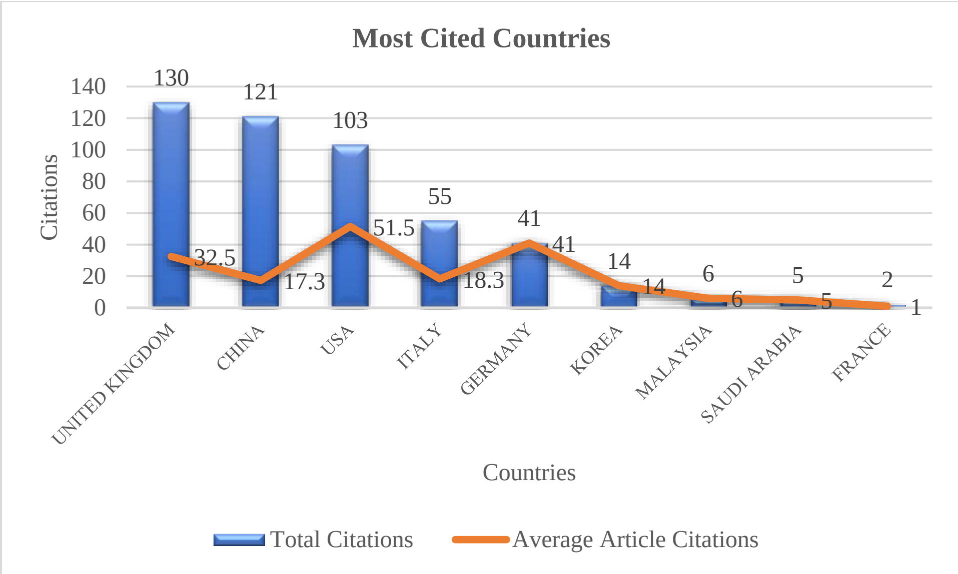

Figure 4. "Most Cited countries."

Table 4 shows the different methodologies used in the reviewed articles. The reviewed articles focused mainly on general FSCs where few authors [23,33–35] discussed how BLCT helps to achieve sustainability. A few of the papers discusses specific FSCs, involving soyabean [14], grains [36], halal [37], milk [38], and mangosteen [39]. The different techniques and tools used in the articles have been discussed in Table 5.

Table 4. Classification of articles based on research methodology.

Sr No	Methodology	Citations	No. of Articles
1	Literature Review	[12,13,23,33–35,40–57]	24
2	Case Study	[37,39,58–61]	6
3	Statistical	[62–67]	6
4	Optimization	[38,68,69]	3
5	MCDM	[70–73]	4
6	Simulation	[74]	1
7	Technology-based	[14,36,75–83]	11
		Total	55

The article also discusses the various platforms used in blockchain for FSCs and its benefits (Table 6). Observations indicate that Ethereum and Hyperledger are the most used platforms. These platforms help in ease of transaction and provide security of data. Articles [7,63,64,66,68] are based on the Ethereum platform, and Hyperledger is used in [61,62,69]. The Ethereum platform, which supports smart contracts and enables true decentralization, is widespread among technologists. The only disadvantages are its slow processing times and high transaction processing costs. The Ethereum community is migrating away from the old proof-of-work (PoW) consensus mechanism to proof-of-stake (PoS), which will be more energy-efficient and reduce usage by half. Using Hyperledger Fabric, you can build closed blockchain applications that provide increased security and speed. Among its benefits is the improvement of data privacy due to the isolation of transactions into channels and high-speed transactions with low latency. A secure hash algorithm (SHA) is an unkeyed cryptographic algorithm that produces a 256-bit-long hash output from a variable-length input. Relay-aided blockchain is used in [81] for sustainable e-agriculture.

Table 5. Techniques and tools used in the literature.

Sr No	Authors	Techniques	Tools
1	[68]	Optimisation	Cooperative game approach
2	[69]		System dynamic modelling
3	[38]		Sequential quadratic programming
4	[70]	MCDM	Decision-making trial and evaluation laboratory (DEMATEL)
5	[71]		Stepwise weight assessment ratio analysis (SWARA)
6	[72]		Decision-making trial and evaluation laboratory (DEMATEL)
7	[73]		Analytic hierarchy process (AHP)
8	[62]	Statistical	Statistical survey
9	[63]		Convenience analysis
10	[64]		Statistical survey
11	[65]		Tobit regression
12	[66]		Conjoint analysis
13	[67]		Likelihood ratio test, choice experiment

Table 6. Platform used in articles.

Authors	Platform Used	Product	Benefits
[14]	Ethereum	Soybean	Transaction, traceability
[76]	Hyperledger Fabric	Food	Food safety, traceability
[75]	Food Supply Chain Traceability System (FSCTS) on Hyperledger	Food	Transparency, traceability
[77]	Ethereum	Food	Food safety, security
[78]	InterPlanetary File System (IPFS) and Ethereum	Agri-food	Traceability
[79]	farMarket	Agri-food	Transparency
[83]	SHA256, Hyperledger, C programming	Fruits + vegetables	Performance, traceability
[80]	Kranti credit based on InterPlanetary File System (IPFS) and Ethereum	Agri-food	Transparency, traceability
[81]	Relay aided blockchain	e-agriculture	Performance
[82]	Ethereum, Smart Contract	Rice	Traceability

Table 7 discusses in detail the review papers. The majority of articles conduct a synthesis and network analysis to understand the current trend, benefits, and challenges observed in FSCs while implementing BLCT. It has been observed that the reviewed articles did not discuss the addition of sustainability to SDGs, nor did they address the idea of achieving net zero using BLCTs in the FSC.

As per the FAO 2021 [84] report, every tenth person sleeps with an empty stomach. Many organisations such as the UN Food and Agriculture Organization, UNEP, UN World Food Programme, and Indian National Program on Food Security are continuously working on food safety, security, and traceability to reduce food losses, wastage, pilferage, and contamination, to meet the demands of the empty stomach [85]. This paper tries to understand how BLCT will help FSCs to increase food safety, security, traceability, and performance. In addition, it also explores how BLCT tries to achieve a TBL and how it can contribute to reaching net zero.

Table 7. Classifying the literature review articles.

Sr. No	Author	Type of Study	No. of Articles	Time Span	Tool Used	Key Objective
1	[12]	SA	-	-	-	Studies the authenticity and traceability of FSC products through BLCT
2	[40]	SA, NA	2482	2013–2018	Vos Viewer	Computational and application aspects of BLCT in the AFSC
3	[41]	SA	-	-	-	Blockchain algorithms for tracing food trade networks
4	[42]	SA	-	-	-	Importance of BLCT in food supply chain management.
5	[33]	SA	-	-	-	Study the application of BLCT in food industry
6	[43]	SLR, NA	71	2008–2018	Gephi	BLCT recent advances, applications, challenges in AFSC
7	[44]	SA, TA	-	-	-	Using BLCT to improve FSC
8	[45]	SA	-	-	-	Agri-food traceability using BLCT
9	[46]	SA	26	2016–2018	-	To study BLCT adoption benefits and challenges in FSC
10	[13]	SA	-	2005–2019	-	Examine the pros and cons of BLCT traceability systems.
11	[47]	SA	200	2016–2019	-	BLCT use in food production, transportation, and safety
12	[48]	SA, NA	48	2016–2019	-	BLCT for monitoring and tracing fresh milk transactions
13	[49]	SA	-	-	-	Adoption of BLCT in the U.S. fresh produce sector and challenges.
14	[23]	SA	74	2018–2021	-	The benefits and drawbacks of BLCT in the FSC
15	[50]	NA	171	2016–2019	R and VOS	Identifying the trend area in agri-blockchain
16	[51]	SA	-	-	-	In BLCT, challenges are encountered in the areas of food fraud, fair trade, food safety, animal welfare, and environmental impact.
17	[52]	SA, SLR		2010–2020	-	To study the application of sustainable AFSC
18	[34]	SLR	69		-	BLCT adoption drivers and barriers, applications, and implementation stages within FSCs
19	[53]	SA	37	2016–2019	-	Current trend of BLCT in food safety is discussed
20	[54]	SA, NA, BA	NA 987, SA 127	1997–2021	Bibliometrix R-Tool	Observing the current trend and technological innovation in AFSC
21	[35]	SLR, semi-structured case	125	2008–2020	-	BLCT in tackling significant difficulties in food traceability accountability, and trust.
22	[55]	SA	-	-	-	An overview of blockchain legislation and regulations
23	[56]	BA, LR	150	2016–2021	Bibliometrix R-Tool, VOS	Scope and significance of blockchain in FSCs
24	[57]	SA	37	-	-	Identify trends and challenges in food safety control using BLCT
25	Author	SLR	55	2018–20 June 2022	R-Tool	How BLCT helps to achieve food safety, security, traceability, TBL and net zero in FSC

"SA—Synthesis analysis, NA—Network analysis, BA—Bibliometric analysis, SLR—Systematic Literature review, TA—Thematic analysis".

2.4. Step 4—Synthesizing Relevant Literature and Evaluation

We have evaluated and reviewed the papers on blockchain with FSC based on specific attributes in terms of benefits and challenges. The benefits explored are transparency (B1), traceability (B2), data security and storage (B3), food safety and quality (B4), supply chain performance (B5), and sustainability (B6). The challenges faced in BLCT are lack of awareness (C1), technological challenges (C2), regulation and governance (C3), and high cost (C4). Table 8 below summarizes the different attributes of the BLCT described in the individual publications.

Table 8. Summary of the evaluation base on attributes categorized.

Sr. No	Authors	Benefits						Challenges			
		B1	B2	B3	B4	B5	B6	C1	C2	C3	C4
1	[12]	✓	✓	✓	✓	✓			✓	✓	✓
2	[58]			✓			✓		✓		✓
3	[40]	✓	✓	✓	✓	✓					
4	[41]		✓		✓	✓					
5	[42]				✓	✓					
6	[68]	✓	✓		✓		✓	✓	✓	✓	
7	[33]		✓		✓		✓				✓
8	[14]		✓		✓	✓					
9	[43]	✓	✓		✓	✓	✓	✓	✓	✓	✓
10	[44]		✓		✓				✓	✓	✓
11	[45]		✓			✓		✓	✓	✓	
12	[46]	✓	✓	✓	✓			✓	✓	✓	✓
13	[13]	✓	✓	✓		✓	✓		✓	✓	
14	[59]	✓				✓			✓	✓	✓
15	[75]		✓		✓						
16	[76]		✓	✓	✓						
17	[70]	✓	✓						✓	✓	
18	[63]		✓	✓					✓		✓
19	[64]		✓			✓			✓		✓
20	[48]	✓	✓	✓	✓	✓		✓	✓		
21	[77]		✓		✓	✓					
22	[71]		✓	✓							
23	[78]		✓	✓	✓	✓			✓		
24	[67]	✓	✓		✓	✓			✓	✓	✓
25	[71]		✓	✓	✓		✓	✓	✓	✓	✓
26	[36]				✓	✓					
27	[37]	✓	✓		✓	✓	✓	✓	✓	✓	✓
28	[69]				✓	✓	✓				
29	[49]		✓		✓			✓	✓		✓
30	[62]	✓							✓		✓
31	[65]		✓		✓			✓	✓	✓	✓
32	[51]	✓	✓		✓	✓	✓		✓	✓	

Table 8. *Cont.*

Sr. No	Authors	Benefits						Challenges			
		B1	B2	B3	B4	B5	B6	C1	C2	C3	C4
33	[79]					✓					
34	[23]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
35	[38]	✓	✓		✓	✓	✓				
36	[73]	✓		✓		✓	✓				
37	[80]		✓	✓	✓						
38	[56]	✓	✓		✓				✓		
39	[52]	✓	✓		✓	✓	✓		✓		✓
40	[66]		✓	✓	✓	✓	✓				✓
41	[67]		✓		✓	✓		✓			
42	[81]					✓	✓				
43	[60]	✓	✓		✓	✓					
44	[39]		✓		✓	✓					
45	[61]				✓				✓		
46	[34]				✓	✓	✓				
47	[74]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
48	[82]	✓	✓	✓	✓						
49	[54]		✓		✓		✓				
50	[35]		✓			✓	✓	✓	✓		
51	[55]				✓			✓	✓	✓	✓

The most common use of BLCT in the FSC has been to increase food traceability and authentication. Blockchain-based traceability enables distributed data sharing across the whole FSC, enabling transparency and accountability [16,45], fraud prevention and traceability, cybersecurity and protection, encryption, and privacy [12,13,16]. Quality and logistics data might be used by smart contracts in blockchains to enable real-time quality control and monitoring, as well as automating logistics planning [86]. This information makes it easy to understand how items went from farmers to processors to wholesalers to grocers and eventually to customers. Indeed, several publications [23,37,38,87] explain the use of blockchain to improve transparency and traceability in the FSC in specific scenarios and review the existing commercial applications. The application of blockchain-based technology in the FSC helps manage sustainability by detecting and resolving sources of contamination [12,52,68]. In [88], the fair-trade movement is discussed, where blockchain informs consumers about the true provenance of the final product along with the fraction of the sale price being returned to the grower. A holistic approach considering the three aspects of sustainability gives a wider view in achieving sustainability in the FSC [54].

The critical success factors (CSFs) for BLCT adoption in FSCs are discussed in several of the papers we selected [59,61,89]. To explain the implications of BLCT on food supply networks, [60] conducted semi-structured interviews and a case study. As part of a case study regarding the dairy industry, the authors of [38] investigated the potential impact of BLCT on sustainable supply chains.

A framework for monitoring and tracing of rice supply chain was proposed in [82]. In [44], a qualitative analysis of the advantages and challenges of implementing blockchain in FSC infrastructure is presented. A content-analysis-based literature review was conducted by [46] to examine the pros and cons of implementing blockchain in FSCs. In [49], the usage of blockchain in a range of scenarios was investigated, emphasizing how widespread use of the technology might assist in overcoming significant challenges in the fresh produce industry. The authors of [61] studied blockchain employment in the food delivery network to promote transparency, agility, information, and food safety improvements.

BLCT adoption by FSC also comes with its own challenges. Challenges such as scalability, throughput and latency issue, regulation problems, and lack of skills are discussed by [71]. The authors of [84] analysed challenges in FSCs, such as security and privacy issues, interoperability and standardization, complexity of system design, and lack of trust and government regulation, using Delphi analysis. In [68], the authors provide an overview of a number of blockchain-based initiatives and projects as well as their challenges and opportunities. BLCT could provide a potential solution to major challenges related to FSCs, according to [51]. The halal food supply challenges are discussed in [37], and a framework using BLCT to overcome it is provided. To address this issue some technical solutions have been discussed by [89], including Proof of Stake (POS) and the InterPlanetary File System (IPFS) for scalability issues, and proxy encryption Interledger, consortium blockchain, on-chain and off-chain storage and many others for security and privacy challenges. Implementation of BLCT has been facing adoption barriers due to the high level of technical knowledge needed.

3. BLCT and Triple Bottom Line Aspects in FSCs

The TBL concept addresses the environmental, economic, and social aspects of the FSC. BLCT contributes to achieving these aspects by monitoring environmental data properly and reducing greenhouse gas emissions. Food supply networks worldwide emit approximately 13.7 billion metric tonnes of carbon dioxide equivalent each year [90]. The most environmentally destructive greenhouse gases are produced by farming, over-usage of land, and transportation, which together act as the largest contributors of greenhouse gases in the FSC (FAO, 2021) [84]. To avoid negative environmental consequences, blockchain might be used to optimize the usage of pesticides, fertilizers, antibiotics, and irrigation [66]. Furthermore, blockchain contributes to environmental sustainability by facilitating adherence to ecological rules. In their paper, [91] indicate that using blockchain increases environmental efficiency by minimizing carbon emissions and helps achieve profit. Thus, SDG 13 (climate action) can be achieved.

Traceability, transparency, accountability, and immutability are the essential elements for the economic and social dimensions of sustainability, as blockchain can assists in enforcing human rights and food security, reducing food waste and food recall, and identifying exploitation and fraud. These aspects are also important since they increase consumer trust and minimize financial exploitation and other risks [92]. The authors of [93] proposed the use of blockchain to shorten the time it takes to process food. They claimed that blockchain's ability to track and trace previously unavailable data can be utilized to improve supply chain procedures, thereby reducing the time taken for a product to reach retail locations. This can make it easier to buy and use the item before it expires, which will reduce food waste [23]. Smart packaging enabled by blockchain can also reduce food waste by providing more accurate information regarding the status of food products, preventing food from being discarded needlessly [94]. In a crisis caused by contaminated food or food recalls, the point of contamination and the affected items may be readily recognized and eliminated, without the need to recall the entire line of products, saving the significant expense involved [95]. Thus, blockchain will significantly impact the achievement of economic sustainability and can fulfil SDGs 9 (industry, innovation, and infrastructure) and 12 (responsible consumption and production).

Blockchains also promote social sustainability by adhering to fair-trade standards. In developing countries, blockchain could analyse what percentage of the price consumers pay for an item is returned to the farmer as well as address consumers' concerns about social welfare and eco-friendly farming methods [23]. Thus, BLCT fulfils SDG 8 (decent work and economic growth). For example, Coca-Cola and the U.S. State Department use BLCT in the sugarcane sector to minimize forced labour. Starbucks is experimenting with blockchain to track, trace and authenticate the ethical production of its coffee and to enhance customer knowledge about coffee-sourcing [96]. In order to achieve sustainable development, stakeholders must be involved, the environmental, economic, and social contexts must be considered, and effective sustainability measures must be supported by effective decision-making [97].

4. Blockchain Application in FSCs

Many industrial sectors are integrating BLCT in their organizations intending to attain sustainability and adhere to the SDG goals as well as setting goals to reduce carbon emissions and achieving net zero. The most visible example of large-scale BLCT implementation in the fresh produce business is Walmart's use of the IBM Food Trust to track green leafy vegetables. Previously, the company worked with IBM to investigate blockchain-based traceability for pork in China and mangoes in the United States. In its ESG report, Walmart is shown that it has been able to achieve SDG goals 2 (zero hunger) and 12 [98]. Carrefour is another significant food store that has used the IBM Food Trust to trial and fully integrates blockchain traceability for select fresh product lines, such as oranges (in Spain and France) and Cauralina and Pomelos tomatoes (in France), which helped to achieve SDG 12.

BLCT could help the Indonesian fishing sector achieve traceability, allowing consumers to recognize where their food comes from while addressing issues such as counterfeiting, unreported, and unrestrained fishing [16]. Cargill Inc. intends to use BLCT to assist customers in tracking turkeys from shops to farmers. Nestlé is experimenting with a new, ground-breaking blockchain network that allows customers to follow their food from farm to plate to improve supply chain transparency. Following the COP21 protocol, most of the companies are setting target of reducing their carbon emission and achieving carbon neutrality by 2040, and BLCT can act as a major contributor in this. Table 9 shows the industry application of BLCT in FSCs and an appropriate SDG justifying it, as well as the net zero target set by the companies.

Table 9. Blockchain Industry Application in FSCs.

Companies	Platform	Partners	Products	Aim	Benefit	Net Zero Target Set by Companies	Relevant SDG	References
Walmart (US)	Hyperledger Fabric	IBM	Mangoes (US), Pork (China)	Ensure the safety of the product by tracking and tracing it. To view the details about the farm, factory, batch number, storage temperature, and shipping.	Food safety, Traceability	2040 for the entire production supply chain through project Gigaton	SDG 2, SDG 12	[99]
JBS	Transparent Livestock Farming Platform	Ecotrace	Beaf Cattle (Brazil)	Using blockchain-based technologies to eliminate food fraud in their supply chains	Food safety, Traceability	2040 for the entire production supply chain	SDG 2, SDG 12	[100]
Nestle (Swiss Food)	IBM Food Trust platform	Rainforest Alliance	Zoegas Coffee (Sweden)	To accompany coffee with reliable, unmodifiable documentation and absolute guarantee of transparency from the plantation to the consumer.	Traceability	20% reduction by 2025, 50% by 2030 and net zero by 2050 for the entire supply chain	SDG 12	[101]
Carrefour (European Retailer)	IBM Food Trust platform	IBM	salmon, tomatoes, honey, eggs, and milk	Tracking its own branded products in Brazil, France, and Spain.	Data storage, food safety, traceability	Reduce emissions by 2040 for the entire supply chain	SDG 2, SDG 12, SDG 14	[102]
Cargil (US)	Hyperledger Grid	iTrade Network	Turkey	Provides consumers with the ability to trace their Thanksgiving turkey's origins using BLCT	Food transparency, traceability	Committed to achieve net zero but has not set a target	SDG 2, SDG 12	[103]
ABInBev (Brewer)	Blockchain platform	SettleMint	Barley, beer	BLCT ensuring that the supply chain of barley from farmers to consumers is transparent and traceable.	Transparency, traceability	Target set for 2040 to achieve net zero for the entire value chain	SDG 2, SDG 12	[104]

Table 9. *Cont.*

Companies	Platform	Partners	Products	Aim	Benefit	Net Zero Target Set by Companies	Relevant SDG	References
Bumble Bee (US)	SAP Cloud Platform Blockchain	SAP	Sea food (Fish)	It would enable consumers to access information about the supply chain's details such as origins, catch sizes, shipping histories, and trade fishing certifications.	Transparency, traceability	Achieve net zero by 2050	SDG 2, SDG 12, SDG 14	[105]
Malaysian Palm Oil Council (MPOC)	Blockchain platform	BloomBac	Palm oil	Consumer will be able to track and trace the real time information about the palm oil which in return will build trust.	Transparency, traceability	Will achieve 66% reduction by 2030 and net zero by 2050	SDG 2, SDG 12	[106]
Kraft Heinz (Italy)	IBM Food Trust platform	IBM	Baby food	To enhance the safety of food products and to trace it to its origin	Food safety, traceability	Target set at 2050	SDG 2, SDG 12	[107]
Tyson and Subway (US)		FoodLogiQ and IBM Food Trust	Chicken	To track the animal in the poultry, to maintain its basic safety condition and to create a transparent supply chain	Food safety, transparency		SDG 12	[108]
Unilever (US)		Provenance	Tea	To reduce the tracking time of tea from the farmers to the shop.	Transparency, traceability		SDG 12	[109]

5. Discussion and Conclusions

Based on the analysis and critically evaluating the articles related to FSCs using BLCT, answers to the research questions, research gap, and recommendations are below.

Even though blockchain has been around for almost ten years, using BLCT in sustainable FSCs is still relatively fresh. Furthermore, while research leads the way in technology development, practical applications, and testing in FSCs are still in their infancy. The lack of clarity in rules and standards, as well as the scarcity of technical skillsets and digital literacy required to use BLCT, are stifling blockchain's expansion in the agriculture and FSC markets in emerging countries. However, there has been a big boom in interest in BLCT during the last two years, as numerous corporations and academic organizations are striving to use this technology into the industrial, financial, agricultural, and societal sectors. Blockchain designs, applications, and business models are fast growing; they are distinguished by decentralized, open-source development and are viewed as disrupting conventional operators in various industries. Many agri-based industries have applied BLCT in their organization and benefited from it.

The study observes that integrating BLCT in FSCs provides greater visibility in SCs, increases transparency, improves food safety, and reduces food waste. In the case of halal FSCs and dairy FSCs, blockchain has increased transparency and benefited companies by ensuring safety and gaining consumers' trust [110,111]. It also helps address the customers' concerns about the origin of products, their safety and quality, by linking the information nodes [112]. BLCT enhances the effectiveness and performance of the FSC through information exchange and transparency, thus reducing the lead time through digitized records and automated workflows. Using this technology, one can reduce operational costs and increase efficiency in the FSC. For example, firms can acquire detailed information on the shelf life of food products to manage their inventory and transportation better, improve profits and avoid waste [93]. Thus, implementation of BLCT improves the profitability of both platform and supplier [112]. By strengthening the immutability, traceability, and transparency within any transaction of the FSC, it also increases trust between its members. Our report also shows that blockchain might be used to decrease product waste and increase supply chain sustainability.

Although many FSC companies are integrating BLCT in their SC, it has been observed that the industrial applications are still in their pilot run and a mass-scale operation is yet to be operated. Because of blockchain innovation's quick yet unpredictable speed, commercial organizations and government bodies find it challenging to decide on a strategy for adapting to BLCT. Another problem is integrating with legacy systems. In many cases, firms have invested years in developing their management systems. It is difficult to go from their current system to the new blockchain without affecting their existing operations. Furthermore, since the technology is transnational and decentralized, regulating it becomes difficult.

The study observes that before implementing blockchain, farmers must first gain a thorough understanding of the technology. Farmers' major concern in many regions of the globe is survival; therefore, they concentrate their efforts on farming and lack competence in advanced technologies. Blockchain technologies also demand a high degree of computation; these resources are limited in developing countries, and implementation is arduous. In [113] it is stated that adoption of BLCT in the supply chain requires standardization, organizational collaboration, and willingness to adopt the technology. As a result, there appears to be a divide in digital competency and access to BLCT between the industrialized and developing worlds. Some authors, however, mention a key point that the majority of such programs are in economically developed nations and hence, they do not address the fundamental problems of developing countries. The authors of [114] emphasize linking technical, organizational, and external concepts for blockchain adoption. Effective collaboration is required to pique managers' and leaders' interest in adopting digital technologies to increase information and resource sharing, decision-making, and to build a synergy between the supplier and the manufacturer, consequently enhancing performance [115]. The authors of [116] conducted an online survey study which revealed that though the participants acknowledged the benefits of blockchain, they were divided on the likelihood of adoption.

Blockchain is a powerful tool for addressing supply chain sustainability and assisting with it [86]. As a technology, blockchain is designed to improve sustainability and achieve net zero in the FSC by minimizing food waste and resource usage, quantifying and reducing carbon footprint, and promoting fair trading. BLCT also helps to resolve carbon emission by reducing transactions and supply–demand irregularities by continuously monitoring, tracking, and recording; simultaneously building trust on the way. For example, Walmart discovered that fresh imports, such as mangoes, might take up to four days to be scrutinized at the border [117]. Hence, by tracking product movements, expediting product inspection, and thus extending shelf life, Walmart will be able to increase sales, simultaneously satisfying the SDG goal. The study also shows that blockchain might be used to decrease the carbon footprint by reducing emissions, paperless transactions, less human intervention, reducing product waste, and increasing supply chain efficiency. Thus, we can say that BLCT helps to achieve sustainability in the FSC and helps to fulfil the SDG 12 goal.

As the future economy strives to achieve net zero, sustainable production and consumption of products have become urgent concerns. Achieving net zero facilitates the achievement of sustainability and fulfilment of the SDGs. From the discussion above, we observe that BLCT helps to meet the triple bottom line aspect, which can further lead to net zero. Net zero implies replacing high-emission processes with low-emission ones [11]. The literature study shows that the work related to applying net zero in FSCs is still dormant. Observing the benefits of BLCT, it has the potential to achieve net zero in FSCs, and future research in this direction will benefit the industries. Though a few studies focus on the sustainability of the FSC, connecting it to SDG goals will benefit the current scenario. The FSC being a very complex supply chain, all the partners of the supply chain need to work equally to achieve net zero.

6. Managerial Insights/Acumen

Based on the analysis of the paper it is observed that BLCT adoption in FSCs has a vast scope in the industry sector. This trend is driven by many factors, including food safety and security, food contamination and fraud challenges, an increase in credibility and efficacy in transactions within the FSC, and the openness and accuracy of food information management systems. It also helps to achieve sustainability, addresses the SDGs, and helps to achieve net zero. BLCT helps to achieve the triple bottom line aspect of sustainability by reducing carbon emissions, increasing productivity and efficiency, and building societal trust.

Regulators and government officials are seeking more innovations in blockchain adoption in order to achieve improved data openness and accountability while providing adaptable, cost-effective, and long-term sustainable solutions. As the paper's analysis reveals, the transition process from existing technologies to blockchain is more of an intellectual transformation than a technological one. Companies or individuals must know and acknowledge the underlying process. The study reveals that adopting BLCT will help to address concerns regarding aging societies, food shortages, resource scarcity, urbanization, waste management, sustainability, and net zero.

Many food companies are collaborating with IBM and other platforms to use distributed ledger technology to improve their sustainability quotient, transparency, traceability, and speed of payments in their supply chains. Global food giants such as Walmart, Carrefour, Nestle, and Unilever are embracing BLCT to track products faster, trace product origins, ensure product safety, adhere to sustainability standards, attain the SDGs, and achieve net zero. BLCT also helps reduce food fraud and contamination as well as food recalls, for BLCT stores the data which will be visible to all supply chain members. BLCT is being incorporated in many FSC businesses to regain and reinforce consumers' trust, acting as a "certificate of excellence". The best example to be cited is Cargill, a global food corporation based in the U.S. that gained consumer trust by increasing the visibility of its product.

Since BLCT is a modern technology, there exists lack of regulations for its governance. It must be investigated how BLCT can be applied in FSC management on a global scale. BLCT is currently neither standardized nor regulated and government and organisations must take the initiative to standardize the technology. Provisions should be made to create awareness and inculcate information among consumers. To achieve sustainability and net zero in the FSC, government and companies must take the initiative and educate stakeholders on the benefits of adopting the innovative solution.

7. Future Research Direction

BLCT, a new technology, can be explored vastly in the FSC domain. A competitive market can lead to BLCT adoption as firms constantly seek to achieve sustainable solutions and competitive advantage. Since the world is moving toward achieving SDG goals and reducing carbon emissions, a study related to aligning SDG goals with BLCT adequately will add volume and depth to the subject. As per the study, BLCT can help achieve Goal 2 (zero hunger) by making the supply chain more productive, sustainable, and resilient, for solving long-term hunger challenges; Goal 3 (good health and well-being) by adhering to the quality standards and providing essential nutrients; Goal 9 (industry, innovation, and infrastructure) by investing in infrastructure and accelerating innovation, thereby leading to sustainable food systems worldwide; Goal 12 (responsible consumption and production) by reducing food waste and spoilage while empowering consumers to make conscious choices; and Goal 13 (climate action) by reducing carbon footprints and achieving net zero (UN Food System Summit, 2021). The analysis will allow researchers to study the impact of BLCT in achieving SDG goals in the FSC, which may further contribute to attaining net zero. Due to Net Zero's relative newness, very little work has been undertaken, leaving a broad scope for future exploration.

Despite the fact that sustainability forms an overarching framework for much of the FSC research, by-products of the FSC must explicitly be considered along with the entire life cycle of a product in order to achieve net zero, not only from a current cost perspective, but also from a total cost perspective. Future research in this direction will help enhance the competitiveness and the survivability index of the FSC.

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Appendix A

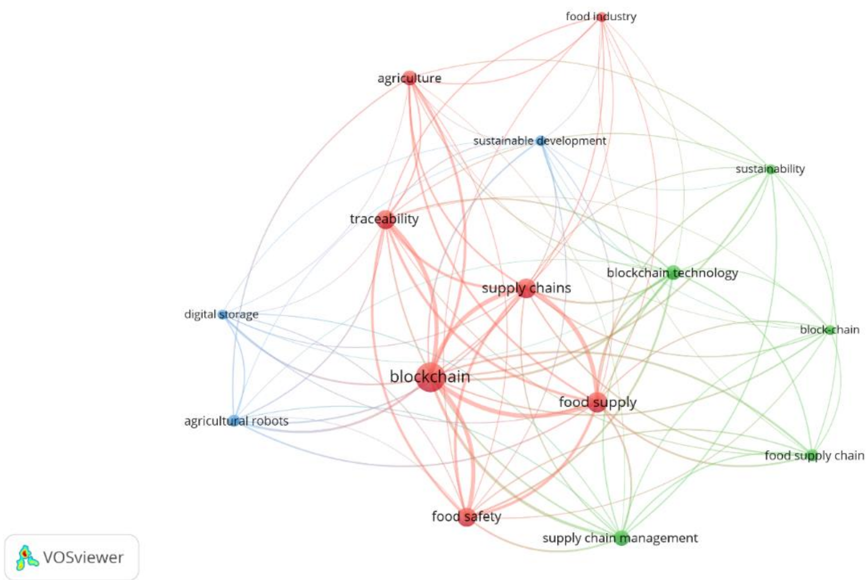

Figure A1. Co-occurrence of Keywords.

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