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Blockchain Adoption for Sustainable Supply Chain Management: Economic, Environmental, and Social Perspectives

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Due to the rapid increase in environmental degradation and depletion of natural resources, the focus of researchers is shifted from economic to socio-environmental problems. Blockchain is a disruptive technology that has the potential to restructure the entire supply chain for sustainable practices. Blockchain is a distributed ledger that provides a digital database for recording all the transactions of the supply chain. The main purpose of this research is to explore the literature relevant to blockchain for sustainable supply chain management. The focus of this review is on the sustainability of the blockchain-based supply chain concerning environmental conservation, social equality, and governance effectiveness. Using a systematic literature review, a total of 136 articles were evaluated and categorized according to the triple bottom-line aspects of sustainability. Challenges and barriers during blockchain adoption in different industrial sectors such as aviation, shipping, agriculture and food, manufacturing, automotive, pharmaceutical, and textile industries were critically examined. This study has not only explored the economic, environmental, and social impacts of blockchain but also highlighted the emerging trends in a circular supply chain with current developments of advanced technologies along with their critical success factors. Furthermore, research areas and gaps in the existing research are discussed, and future research directions are suggested. The findings of this study show that blockchain has the potential to revolutionize the entire supply chain from a sustainability perspective. Blockchain will not only improve the economic sustainability of the supply chain through effective traceability, enhanced visibility through information sharing, transparency in processes, and decentralization of the entire structure but also will help in achieving environmental and social sustainability through resource efficiency, accountability, smart contracts, trust development, and fraud prevention. The study will be helpful for managers and practitioners to understand the

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procedure of blockchain adoption and to increase the probability of its successful implementation to develop a sustainable supply chain network.

Keywords: blockchain, sustainable supply chain, green supply chain, triple bottom-line, circular supply chain, traceability

1 INTRODUCTION

In the past, the economic benefit was the main focus of supply chain professionals. However, due to a high rate of environmental degradation, the emphasis is shifted from economic to social and environmental sustainability (Tseng et al., 2019; Gupta et al., 2020). The pressure from stakeholders such as government organizations, regulatory bodies, and customers is forcing the firms to redesign their internal and external supply chain structures, according to environmental concerns and social needs (Srivastava, 2007; de Oliveira et al., 2018; Manupati et al., 2019). Green supply chains and sustainable practices are an important area of research, and it includes a series of green initiative activities in all processes (Silvestre et al., 2018; Rezaei Vandchali et al., 2021). The supplementary concepts used in sustainability are the reuse, recycle, and circular supply chain (Koberg and Longoni, 2019). The green and sustainable practices are adopted by different firms to ensure the welfare of society through waste reduction, emission reduction, and energy usage optimization (Agyabeng-Mensah et al., 2020). There are many innovative technologies that provide a competitive advantage to firms (Kamble S. S. et al., 2021). Advancement in technologies is very extensive, and each of these technologies has effects on the green initiative and social sustainability of the firms (Kouhizadeh and Sarkis, 2018). Among all recently developed technologies, blockchain (distributed ledger) has significant effects on the sustainability (Kouhizadeh and Sarkis, 2018).

Blockchain is a distributed accounting system with automatic transaction execution, which is used to maintain the growing data (Wu et al., 2017). Its main characteristics are high consistency, data veracity, traceability, and cybersecurity. Blockchain is considered as a technology that will bring breakthrough in the supply chain as it is a transparent and temper proof system, which will improve the tracking and tracing system (Badia-Melis et al., 2015; Wu et al., 2017; Wang Y. et al., 2019a; Pournader et al., 2019; Behnke and Janssen, 2020; Feng et al., 2020; Ozdemir et al., 2020; Xu et al., 2020; Garaus and Treiblmaier, 2021). Blockchain can be beneficial for the food supply chain in many aspects such as quality preservation, fraud prevention, anti-counterfeiting, and cost reduction (Coronado Mondragon et al., 2020). Effective traceability is required in a complete value chain as lack of transparency in one firm will affect the entire supply chain (Hu et al., 2013). The other factors which drive for the adoption of blockchain are consumer trust, risk management practices, regulatory requirements, high consistency, and data veracity (Bosona and Gebresenbet, 2013). Blockchain will shift the "product-based economy" to an "information-based economy" (Pazaitis et al., 2017).

There are various studies published in the field of blockchain in the supply chain under different titles. The main objective of these studies was to analyze the effects of blockchain adoption on the overall performance of the supply chain. Galvez et al. (2018) examined the capability of blockchain and concluded that traceability and transparency can be improved using blockchain. Kamilaris et al. (2019) reviewed the effects of blockchain in the agri-food supply chain and concluded that blockchain is a step toward transparency in the food supply chain. Feng et al. (2020) provided review of different characteristics of blockchain and proposed a framework for adoption of blockchain in the food traceability system. Hosseini Bamakan et al. (2021) and Han et al. (2021) provided the deep insights into the application of blockchain in pharmaceutical cold chain and identified the different challenges of blockchain adoption. Lim et al. (2021) used descriptive analysis and explored different themes and methodologies used for the adoption of the blockchain. Niknejad et al. (2021) conducted a review on the blockchain using graphical mapping of the bibliographic information. Main emphasis of researchers is the traceability of products, through emerging modern technologies. Wamba and Queiroz (2020) discussed the techniques by which different sectors such as agriculture, e-commerce, and public services gained a competitive advantage through the effective use of blockchain. Liu et al, (2021) examined the literature about the information and communication technologies in agriculture. Rejeb and Rejeb, (2020) and Park and Li, (2021) concluded that all the indicators of sustainability can be improved using blockchain.

Blockchain adoption in the supply chain is at a very early stage, although its application in different sectors is increasing rapidly (Choi et al., 2018; Kuo and Kusiak, 2019). Blockchain has a potential to reshape the entire supply chain by incorporating sustainable activities with a special focus on environment protection and social reforms (Tsai et al., 2021). There is limited literature available which covers that how blockchain will impact the supply chain in terms of its sustainability (Khanfar et al., 2021). The previous literature only covers the economic aspects of blockchain in the supply chain. Moreover, application areas for most of the literature reviews of blockchain are the food and agriculture supply chain and cold supply chain, in which transformational capabilities of blockchain through different attributes such as traceability, transparency, and cybersecurity are analyzed (Sunmola et al., 2021). Challenges and financial barriers in adoption and implementation of the blockchain are widely discussed in the previous literature. There exists a research gap as limited literature is available on the impact of blockchain on green practices in the supply chain. Similarly, the social impacts and challenges of blockchain adoption are discussed in the past, but the concept of social sustainability is very broad, which includes other dimensions such as community welfare, regional development, and employability. The

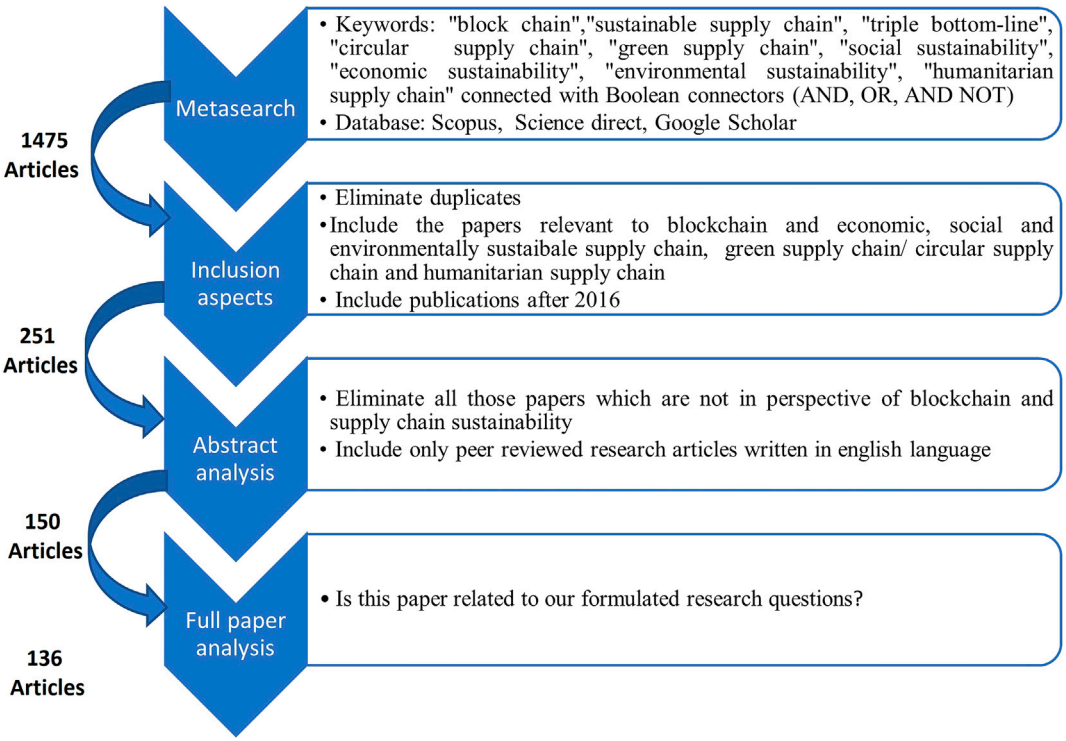

FIGURE 1 | Protocol for the systematic literature review.

humanitarian supply chain is the core topic of researchers, and the effects of digitalizing the supply chain on risk management and sustainability are still need to be explored, especially during the time of crisis. These research gaps are addressed in the current study.

The main objective of this study is to collect the articles from leading journals on the theme of blockchain in perspective of the sustainable supply chain. In this research, articles were collected and categorized on the basis of three basic indicators of (economic, environmental, and social) sustainability. Different models, frameworks, and case studies are included under the paradigm of sustainability. The scope for social sustainability is widened, and articles related to social welfare and the humanitarian supply chain are also included. The main contribution of this study is that it will not only provide the insights about the use of blockchain for the development of the green supply chain but also will help the researchers to evaluate this new technology for its environmental and social impacts as well. The article has the following structure. **Section 2** covers the methodology of the systematic literature review. **Section 3** is about the basic overview on the supply chain sustainability and blockchain. **Section 4** has a detailed review about the economic sustainability in the supply chain using blockchain. **Section 5** covers all the contents of the green supply chain/circular supply chain. **Section 6** describes the advantages of blockchain in the humanitarian supply chain and its social aspects. **Section 7** covers the practical implications of blockchain. **Section 8** is about conclusion.

2 METHODOLOGY OF THE SYSTEMATIC LITERATURE REVIEW

A literature review should be systematic in methodology, explicit in explaining the procedures, comprehensive in scope for all the included material, and reproducible for the people who are reviewing the same topic (Okoli and Schabram, 2010). The difference between traditional literature review and systematic literature review is that systematic review has clearly defined questions, comprehensive relevant study, and properly evaluated and synthesized results, and its main purpose is to make a summary of the best available research on a relevant topic transparently (Habib et al., 2016). Systematic literature review is a rigorous method to assess and evaluate the research in any area. For this research, systematic literature review (SLR) was adopted. There are four steps in a systematic literature review. These steps include planning, searching on a particular topic, screening, and extraction. Protocol for the systematic literature review is given in "**Figure 1**."

Planning: it is the phase in which research questions are formulated. The questions should be clear and explicit. The research questions in this research are the following:

RQ 1: What is the current literature on the intersection of blockchain and the sustainable supply chain?

RQ 2: What are the gaps and future research trends in improving the sustainability of the supply chain using

blockchain from economic, social, and environmental perspectives?

Searching: keywords were developed to search the articles relevant to blockchain and the sustainable supply chain, and these keywords were based on research questions. These articles were collected by using keywords: "blockchain" AND "logistics" OR supply chain" AND "social sustainability, AND "environmental sustainability," OR "green supply chain," AND "economic sustainability," AND "circular supply chain" AND "humanitarian supply chain". Scopus-indexed journals and the Scopus database were selected for data collection. Other forums such as Google Scholar and ScienceDirect were combined for search. The publications were selected from 2016 to 2022 because the concept of blockchain is at its early development stage.

Screening: the inclusion and exclusion criteria were used for the objectivity of research.

Inclusion criteria: the scope of this work was to study about blockchain and sustainability of the supply chain, so all articles are relevant to the application of blockchain in the green supply chain, circular supply chain, and the effects of blockchain on social sustainability. Moreover, articles related to economic sustainability through traceability, transparency, and visibility were also selected. We have included articles from peer-reviewed journals and limited conference articles, which are relevant to the previously described questions.

Exclusion criteria: the main emphasis of this study was on blockchain and triple bottom-line aspects of sustainability in the supply chain. The articles which do not fall in this category were excluded from the list.

Extraction: in the extraction phase, the articles are divided into three categories based on three dimensions of sustainability. The first category of articles is based on blockchain and economic sustainability in the supply chain. In this category, different characteristics of blockchain such as traceability, visibility, and transparency are discussed in detail. The second category is the blockchain-based green supply chain and circular supply chain. In the third category, articles are relevant to social sustainability and humanitarian supply chain management.

3 RESEARCH ON THE INTERFACE OF BLOCKCHAIN AND SUSTAINABLE SUPPLY CHAIN MANAGEMENT

Blockchain helps in achieving environmental sustainability as it helps companies to reduce carbon emissions (Xu et al., 2019). It creates a reputation-based mechanism that encourages participants to find the long-term solution to emissions because all the participants are fully aware of financial benefits of being a well-reputed organization (Esmaeilian et al., 2020). Blockchain can help in the detection of all counterfeit products (Duan et al., 2020). Tracking the products can help in reducing the rework which will help in reducing resource utilization and gas emissions (Badia-Melis et al., 2015; Li et al., 2020). If the manufacturing process becomes green, then environment friendly customers will prefer to purchase the green products (Martins and Pato, 2019). One method to achieve environmental sustainability is the imposition of a carbon tax as the product becomes expansive with a high tax of the carbon footprint, then the customer will prefer the product with a lower price (Lim et al., 2021). Blockchain can help in reducing the carbon footprint in the journey of products toward the end user (De Sousa Jabbour et al., 2018). The supply chain environmental analysis tool (SCEnAT) recommends an outline that will evaluate the emission of carbon of all entities used in supply chains, and its latest version is integrated with Internet of Things (IoT), blockchain, and artificial intelligence (Koh et al., 2013). IBM is developing green assets based on blockchain, which will help the organizations to track, measure, and reduce carbon emissions (Meyer et al., 2019; Upadhyay et al., 2021). The main framework for this research is shown in "**Figure 2**." The features of blockchain include consensus among partners, cybersecurity, immutability, smart contracts, and decentralization of information on a distributed ledger (Viriyasitavat et al., 2018). This excellent information sharing system will improve the traceability, transparency, trust, and responsiveness of the supply chain. Through smart monitoring and controlling of carbon emissions, the environmental sustainability can be improved. Similarly, through smart contracts, carbon taxation policy can be imposed and monitored regularly. The traceability of products and responsiveness of the supply chain will increase the trust of customers (Rodríguez-Espíndola et al., 2020; Thakur and Breslin, 2020). All of these characteristics of blockchain will be useful for monitoring and controlling the overall process of the humanitarian supply chain and firms involved in the supply chain will become socially more responsible. Total articles in this research article are divided into three categories.

1) Articles related to economic sustainability through different features of blockchain such as traceability, transparency, accountability, and visibility.
2) Articles relevant to the model development, theoretical framework, case studies, adoption challenges for blockchain in the supply chain, emissions reduction, green supply chain, and circular supply chain.
3) Articles related to the challenges in implementation of blockchain in the supply chain, its societal impacts, and humanitarian supply chain.

4 ECONOMIC SUSTAINABILITY IN THE SUPPLY CHAIN

Digitalization is transforming the supply chain; specifically, the food supply chain and consumer are more focused on environmental and socially sustainable products (Kittipanya-ngam and Tan, 2019). As a result, traceability, sustainability, and safety have become the core issues (Queiroz and Fosso Wamba, 2019; Wang Y.et al., 2019b). Blockchain technology is regarded as a disruptive and innovative technology and is considered to be the primary tool in the industry 4.0 (Ramadurai and Bhatia, 2019; Thylin and Duarte, 2019). The various features of the blockchain include traceability,

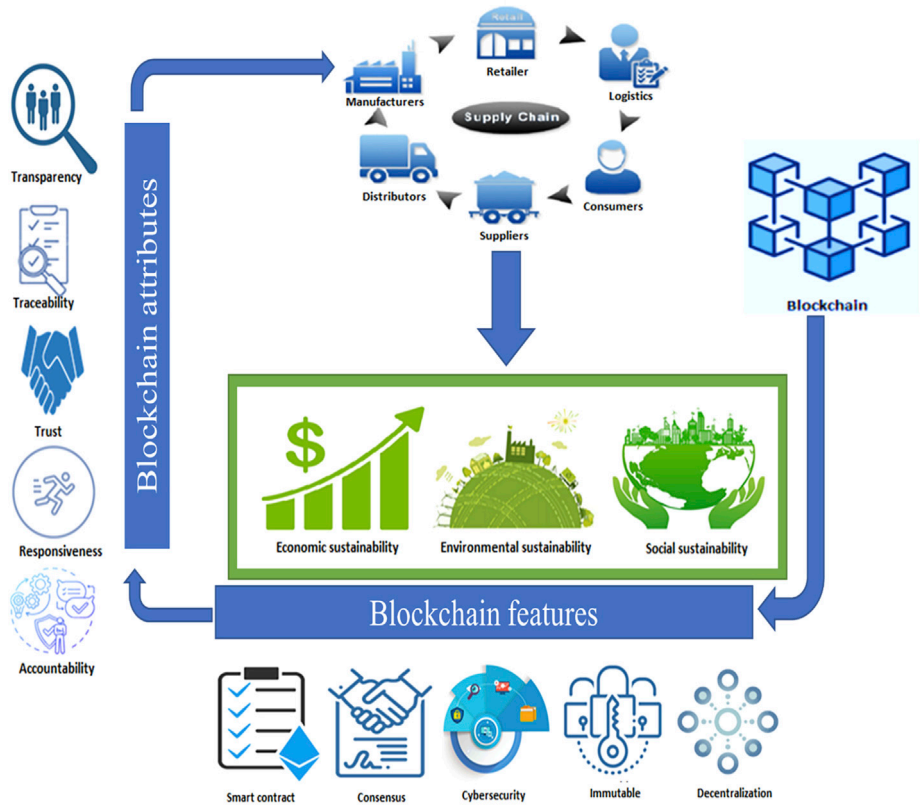

FIGURE 2 | Conceptual framework of transformation of the supply chain to attain triple bottom line through blockchain.

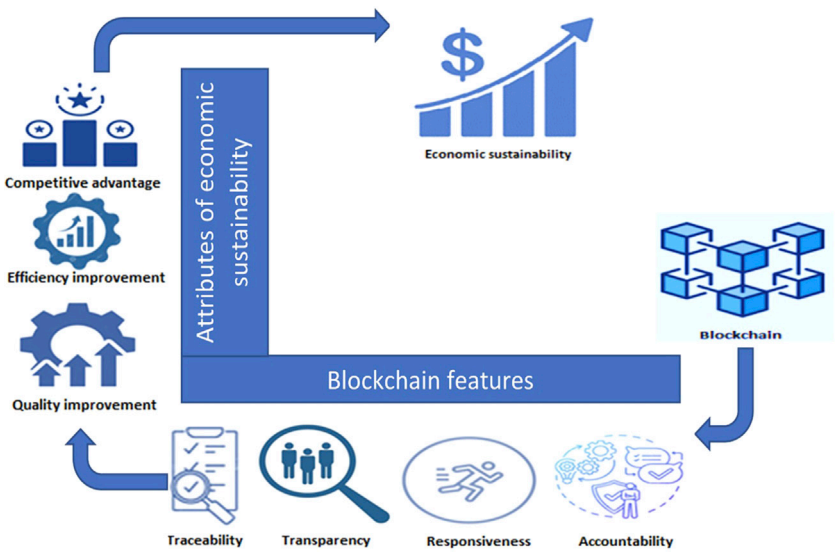

FIGURE 3 | Conceptual framework of economic sustainability of the supply chain through blockchain.

TABLE 1 | Models and framework development for the blockchain-based supply chain with economic sustainability in the agriculture, food, and healthcare sectors.

	Author	Objective	Solution approach	Area of application	Limitations and future research direction
1.	Feng, (2017)	The authors have built traceability system "HACCP" using blockchain.	Hazard analysis and critical control	Agriculture and food sector	Blockchain technology is rudimentary, and its main challenge is a scalability issue.
2.	Caro et al. (2018)	Authors developed and used a case in which they used two different blockchain implementation domains, Ethereum and Hyperledger.	Blockchain implementation through Hyperledger	Agriculture and food sector	Single-language in smart contracts and static structure for a record are the limitations.
3.	Shangping Wang et al. (2019)	Authors have proposed a blockchain-based traceability system.	Prototype development	Agriculture and food sector	The model should be tested through a large-scale practical case study.
4.	Dasaklis et al. (2019)	The researchers have developed a framework that defines the granularity levels of products based on the unique characteristics.	Conceptual framework using smart contracts	Agriculture and food sector	The proposed research is conceptual and requires empirical validation.
5.	Bechtsis et al. (2019)	This research is based on the two-stage supply chain of containerized food.	Hyperledger Fabric framework	Agriculture and food sector	The cost for the implementation of this framework is very high.
6.	Ronaghi, (2020)	The study is about the development of a model which evaluates the maturity of blockchain in the field of the agricultural supply chain.	Ranking the dimensions of blockchain	Agriculture and food sector	Their research is limited to a single-developing country.
7.	Machado et al. (2020)	A framework based on blockchain for effective project management is devised to solve the complexity of the record-keeping issue.	Architectural development using smart contracts	Agriculture and food sector	The developed framework should be empirically validated.
8.	Thakur and Breslin, (2020)	Authors have developed a product serialization method for the security of the supply chain of perishable goods.	Development of the product serialization method	Agriculture and food sector	Future research should be based on the use of this method for the automation of the product recall system.
9.	Liu et al. (2020)	This article proposes a structure of the supply chain based on integration of big data and blockchain.	Operation research	Agriculture and food sector	The proposed model does not explain the complex supply chain.
10.	Sensen Hu et al. (2021)	Researchers have constructed a framework of the organic agriculture supply chain (OASC) by leveraging the immutability of blockchain.	Conceptual framework	Agriculture and food sector	Blockchain technology must be explored for the balance between cost and efficiency.
11.	Eluubek Kyzy et al. (2021)	This article is about the establishment of the consortium through blockchain with the cybersecurity system.	Establishment of consortium based on blockchain	Agriculture and food sector	Future study should be based on economic and environmental aspects of sustainability.
12.	Maity et al. (2021)	The authors have developed and optimized a model of the supply chain of sausage.	Operation research	Agriculture and food sector	The research should be expanded to a large scale by considering the network of suppliers.
13.	Varriale et al. (2021)	The authors investigated the improvement in order and disruption event through modern technologies.	Simulation-based research	Agriculture and food sector	Technology implementation, management, and personal costs were not considered in the study.
14.	Kim and Laskowski, (2018)	In this research, the authors have analyzed the traceability ontology to convert some of its representation to smart contracts.	Conceptual research	Pharmaceuticals	This is conceptual research and requires validation through a case study.
15.	Yong et al. (2020)	The purpose of this article is to develop a "vaccine blockchain" system.	Machine learning	Pharmaceuticals	Future work should be based on real data sets.
16.	Yang, (2021)	In the medical field, the false report spreading trend is increasing, so tracing and tracking is required to gain credibility in the supply chain.	Prototype development	Healthcare sector	Validation of the prototype on a larger scale is required in future research.
17.	Zhu et al. (2021)	Authors have developed a method for the tracing of information on infectious diseases.	Programming using Python 3.7	Healthcare sector	The extension of this research may be based on the use of Hyperledger Fabric.

privacy, immutability, decentralization, and consensus mechanism (Sikorski et al., 2017). The outcomes of the blockchain are agility, resilience, responsiveness, and sustainability (Stranieri et al., 2021). The conceptual framework of economic sustainability of the supply chain using blockchain is shown in "**Figure 3**." The main features of blockchain are its transparency, effective traceability, responsive supply chain, and accountability as discussed in previous sections. By incorporating these features in supply chain processes the quality of products or services will be improved (Chang Y. et al., 2019; Bechtsis et al., 2019). It also will improve the process efficiency and thus will provide the competitive advantage.

4.1 Model Development, Framework Related to Economic Sustainability, and the Blockchain-Based Supply Chain in Agriculture, Food, and Healthcare Sectors

Blockchain is an excellent mechanism of sharing information. Its applications in the food, agriculture, and healthcare sectors

TABLE 2 | Models and framework development for the blockchain-based supply chain and economic sustainability for different sectors.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Sahebi et al. (2022)	The authors have identified the enablers of blockchain in the renewable energy supply chain.	Fuzzy interpretive structural modeling	Energy sector	Validation through a case study should be conducted in future research.
2.	Francisco and Swanson, (2018)	The unified theory of acceptance and use of technology was used to develop a framework.	Conceptual framework	Technology sector	The impact of company culture and social acceptance should be analyzed for blockchain adoption.
3.	Longo et al. (2019)	Authors have designed a software connector for the blockchain and enterprise information systems.	Developed software connector	Technology sector	A comprehensive study is required to explore the benefits of blockchain.
4.	Fan et al. (2020)	Successful adoption of blockchain depends on the awareness of customers about traceability issues.	Operation research	Technology sector	Empirical validation is required for a proposed model.
5.	Bai and Sarkis, (2020)	This article presents the performance measures of blockchain in terms of sustainability.	Hybrid group decision, integrated hesitant fuzzy set	Technology sector	It is a conceptual model, and it lacks the real-world practical application.
6.	Yadav and Singh, (2020b)	The main task of this article is to justify that blockchain is more sustainable.	Quantitative research methodology	Technology sector	The findings of this article cannot be generalized due to the limited number of respondents.
7.	Helo and Shamsuzzoha, (2020)	This article is about the development of the portal system for effective tracing and tracking.	Cloud-based portal	Technology sector	Integration of blockchain with ERP and transport management systems should be tested empirically.
8.	Budak and Çoban, (2021)	The purpose of this article is to evaluate the impacts of blockchain adoption in the supply chain.	Cognitive maps method	Technology sector	Future studies should be based on the use of cognitive maps in different industrial sectors.
9.	Erol et al. (2022)	The authors have ranked the most beneficial critical functions of the sustainable supply chain.	Fuzzy SWARA	Technology sector	The research has employed very limited number of criteria and experts.
10.	Figorilli et al. (2018)	This research is about the development of architecture for the wood supply chain.	Conceptual architecture	Wood supply chain	This conceptual architecture should be empirically validated.
11.	Shuchih Ernest Chang et al. (2019)	The authors have proposed a framework of blockchain using smart contracts.	Conceptual framework	Supply chain re-engineering	The future study should be based on using this proposed framework in different industries.
12.	Li et al. (2019)	The authors have developed a prototype-automated customer service based on automated machine learning and blockchain.	Automated machine learning	Customer service sector	Their proposed platform was lacking privacy issues.
13.	Montecchi et al. (2019)	They have developed the framework for the provenance knowledge based on blockchain.	Development of framework	Risk mitigation	This is a conceptual research study and is not validated empirically.
14.	Helo and Hao, (2019)	Authors developed a solution for the tracking of parcels.	Development of the logistics monitoring system	Postal services	Scenario analysis will measure the qualitative and quantitative effects of this proposed model.
15.	Liu and Li, (2020)	The focus of this research is e-commerce.	"Hierarchical deterministic wallet" technique	E-commerce	The research is not empirically validated.
16.	Naderi et al. (2021)	This article is about the calculation of the consumed energy in the sustainable supply chain.	Exergy analysis	Energy sector	Uncertainties in the supply chain network are not considered.
17.	Tian et al. (2020)	Authors used the algorithm of long- and short-term memory to predict the satisfaction of customers.	Machine learning algorithm	Urban logistics	A limited number of indicators are used to measure customer satisfaction.
18.	Wu et al. (2017)	They provided a crowd-validated framework that balanced the problems of contemporary enterprises.	Conceptual framework	Shipment industry	For complex networks in real scenarios, several challenges may be encountered for this model.
19.	Yiu, (2021)	Blockchain is considered the best solution for counterfeiting and malicious modifications.	Conceptual research	Supply chain industry	This is conceptual research and is not validated empirically.
20.	Asuncion et al. (2021)	Authors have performed an assessment for the different layers of blockchain for identification of different challenges.	Graph-based approach	Defense industry	In this research, the used case study was very simple at the pilot phase.
21.	Yousefi and Mohamadpour Tosarkani, (2022)	The study is about the relation of blockchain and supply chain sustainability through smart contracts, traceability, and transparency.	Fuzzy cognitive map	Mineral supply chain	Blockchain is at a very early stage, and it lacks experience experts.

are rapidly increasing due to the traceability system. Perishable foods, vaccines, and cold supply chains require this disruptive technology to control the wastage of food and temperature-controlled pharmaceutical products (Óskarsdóttir and Oddsson, 2019). The researchers have developed different models and frameworks in the perspective of economic sustainability through transparency, traceability, visibility, and accountability in supply by using blockchain. A list of differently proposed frameworks and models related to blockchain and economic sustainability in the supply chain is given in "**Table 1**." The main features of these models are as follows:

1) Most of the developed models and proposed frameworks are based on the agriculture and food sectors, and there are some articles relevant to the pharmaceutical and healthcare sectors.
2) The main emphasis is to develop models and frameworks based on smart contracts and for traceability solutions as contracts can help develop and improve the relationship among all the network of the supply chain. It improves data sharing among all the actors, and it is a continuous improvement process.
3) Some articles are based on the conceptual study and other solution approaches are used including Ethereum and Hyperledger Fabric, machine learning, programming using Python, "SWARA" method, serialization method, mathematical modeling, and prototype development.

For many years, food security has been a large problem. The old methods for logistics and transportation of agri-food are not feasible to match the demands of the market. The traceability system, based on radio frequency identification, for the agri-food value chain should be designed for the safety of food. In this perspective, Bechtsis et al. (2019) presented a framework that integrates all the information of containerized food on a single and secured platform of sharing information called the blockchain. Ronaghi (2020) researched in three stages: in the first phase, they used the SWARA method for ranking different dimensions of blockchain: in the second phase, they designed a model for the evaluation of maturity of blockchain for the agriculture sector. In the third phase, they evaluated their model using a questionnaire. Their findings showed that transaction records and smart contracts are of higher importance in all dimensions of the supply chain.

4.2 Model Development, Framework Related to Economic Sustainability, and the Blockchain-Based Supply Chain in Different Sectors

One of the basic benefits of blockchain is the reliable transaction of payment and money transfer (Rubio et al., 2018). There are a large number of examples for the successful implementation of blockchain in the industrial sector, product development, and governance mechanism. The main purpose for using this application is to restructure the supply chain (Sundarakani et al., 2021). Different models and framework development based on blockchain in perspective of economic sustainability for different sectors are listed in "**Table 2**." Some important points are as follows:

1) Specific articles are related to the technology implementation, software development, or different characteristics of blockchain. These are categorized as the technology sector.
2) The other areas of applications are postal services, wood supply chain, energy sector, urban logistics, and defense industry.
3) Various articles are conceptual; other solution approaches used are fuzzy cognitive map, automated machine learning, hierarchical deterministic wallet, cloud-based portal, graph-based approach, development of blockchain-based logistics monitoring system (BLMS), fuzzy MICMAC, fuzzy analytic network process, quantitative analysis, and operation research techniques.

The main features of the blockchain are decentralization, audibility, and cybersecurity (Hu D. et al., 2021). Blockchain is a transparent system across the whole supply chain as data cannot be manipulated due to minimum role of mediators. In this background, Yadav and Singh (2020b) compared the performance of a blockchain-based supply chain and a traditional supply chain. They identified the characteristics of blockchain and analyzed them through modeling on fuzzy-interpretative structural modeling. Naderi et al. (2021) provided an optimized model which was multi-objective and based on exergy analysis for the sustainable supply chain. The model was simulated on real-time data in the dairy sector of Iran. The rapid changing of the demand of consumers due to urbanization is continuously affecting the logistics industry, which is a challenge for a logistic service provider. In this background, Tian et al., (2020) proposed an evaluation approach for customer satisfaction based on blockchain. A simulation based on experimental work was performed, and the feasibility was evaluated for the proposed model.

4.3 Case Studies Relevant to Economic Sustainability in the Blockchain-Based Supply Chain in the Agriculture, Food, and Healthcare Sectors

The basic characteristic of blockchain is the shared information on equality base as no individual has access to change the information without the approval of other participants (Liu et al., 2020). Case studies and empirical pieces of evidence of blockchain are not in the mature stage; however, different researchers have conducted case studies and developed theoretical inferences. Different case studies conducted in the agriculture, food, dairy, aquaculture, and pharmaceutical sectors are listed in "**Table 3**."

1) The different solution approaches used in these case studies are Ethereum smart contracts, conjoint analysis, analytical hierarchy process, qualitative and quantitative research methodology, and prototype development.

TABLE 3 | Case studies related to economic sustainability in the blockchain-based supply chain in agriculture, food, and healthcare sectors.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Paul et al. (2021)	A conceptual framework was developed related to the tea supply chain.	Quantitative research methods	Agriculture and food sector	It should be explored that how blockchain will solve the legal and ethical issues in the tea supply chain.
2.	Salah et al. (2019)	The authors have used smart contracts for the traceability of soybean in agriculture.	Framework development	Agriculture and food sector	Future work should be based on governance structure, scalability, standards, and regulations of blockchain.
3.	Kittipanya-ngam and Tan (2019)	The researchers have proposed a framework of the food supply chain and validated by a firm in Thailand.	Case studies	Agriculture and food sector	The validation of their framework requires a comprehensive study on other types of food supply chains.
4.	George et al. (2019)	The authors developed a prototype for the restaurants.	A prototype implementation	Agriculture and food sector	The prototype is specific to the food supply chain of restaurants.
5.	Behnke and Janssen, (2020)	This article recognized the boundary conditions to enhance traceability.	Qualitative methods	Agriculture and food sector	Short-term solutions are not discussed for quick implementation of blockchain.
6.	Bumblauskas et al. (2020)	The main goal of this article is to explain the adoption of blockchain in the supply chain of eggs.	Case studies	Agriculture and food sector	It is difficult to quantify the benefits of blockchain.
7.	Köhler and Pizzol, (2020)	This article provides insights about the benefits of social and environmental sustainability.	Qualitative research methodology	Agriculture and food sector	A longitudinal study is required for the validation of conclusions.
8.	Saurabh and Dey, (2021)	The research is based on a case study of the grape wine supply chain.	Rating-based conjoint analysis	Agriculture and food sector	Their proposed architecture should be expanded at the multistage level.
9.	Cao et al. (2021)	The main aim of this study is to analyze the trust development through blockchain in the beef supply chain.	Case-based prototype development	Agriculture and food sector	Future studies should consider a large number of producers, consumers, and other stakeholders.
10.	Stranieri et al. (2021)	Authors have proposed the conceptual framework based on performance dimensions such as flexibility, food quality, responsiveness, efficiency, and transparency.	Qualitative research methodology	Agriculture and food sector	The research is specific to only three firms with an already well-structured supply chain.
11.	Niu et al. (2021)	Researchers have investigated the effects of blockchain on suppliers and retailers.	Model development	Agriculture and food sector	The developed model has not considered the output uncertainty.
12.	Mukherjee et al. (2021)	The objective of this article is to highlight the benefits of blockchain in terms of sustainability and resilience.	Analytical hierarchy process	Agriculture and food sector	The proposed method should be used for the multi-tier supply chain.
13.	Masudin et al. (2021)	The finding of authors is that blockchain affects the traceability system, and effective tracing has positive effects on the performance.	Quantitative research methodology	Agriculture and food sector (cold supply chain)	A comprehensive study is required to determine different variables required to measure the performance.
14.	Casino et al. (2020)	The authors have developed secure architecture for the food supply chain.	Validation through a case study	Dairy sector	Blockchain technology has a limitation as it cannot store a large amount of data.
15.	Tan and Ngan, (2020)	The study is specific to the dairy sector where blockchain is used to solve the traceability issues.	Qualitative research methodology	Dairy sector	The research is conducted in the prospect of only a single country, Vietnam.
16.	Kshetri, (2018)	The study explains the different benefits of the implementation of blockchain.	Case studies	Retail, defense, fishing, and pharmaceuticals	The study did not consider the dynamic capabilities of all the companies.
17.	Azzi et al. (2019)	The authors have conducted case studies to analyze how blockchain can provide a reliable, authentic, and transparent system.	Validation through case studies	Food and pharmaceutical industry	A longitudinal study is required to validate the long-term benefits.
18.	Tönnissen and Teuteberg, (2020)	The authors have conducted case studies to analyze the effects of blockchain for the logistics industry.	Validation through case studies	Multiple sectors	Case studies only consider the static view and do not consider the dynamic models.
19.	Kshetri, (2021)	In this article, multiple case studies are analyzed in developing countries.	Case studies	Retailers and the food sector	Framework should be developed integrating IoT, RFID tags, and satellite imagery.
20.	Dwivedi et al. (2020)	The presented blockchain-based scheme is about the pharmaceutical supply chain.	Development of the blockchain-based mechanism	Pharmaceutical industry	The proposed scheme does not consider the traceability of temperature-controlled drugs.
21.	Badhotiya et al. (2021)	This study is about blockchain in the supply chain of pharmaceuticals.	Assessment model	Pharmaceutical industry	A longitudinal study is required to analyze long-term use of blockchain.
22.	Uddin, (2021)			Pharmaceutical industry	

(Continued on following page)

TABLE 3 | (*Continued*) Case studies related to economic sustainability in the blockchain-based supply chain in agriculture, food, and healthcare sectors.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
		In this article, the authors have proposed a blockchain-enabled Medledger system to track and trace the drugs.	Drug traceability framework		Hyperledger Fabric technology is facing challenges such as governance, scalability, and privacy.
23.	Adarsh et al. (2021)	The research is based on the integrated technology of big data and blockchain.	Development of mobile application	Healthcare sector	The extension of a proposed application in developed countries is the future scope.
24.	Garrard and Fielke, (2020)	The authors have explored the ability of blockchain to the provenances of the supply chain.	Qualitative research methodology	Aquaculture enterprises	The concept of traceability is partially applied in this research.
25.	Tsolakis et al. (2021)	The research is about the design of a food supply chain based on blockchain.	Case study	Aquaculture enterprises	There was limited participation of respondents.

2) The main characteristics of blockchain in the supply chain such as flexibility, efficiency, responsiveness, and transparency are discussed in detail.

Blockchain is used to keep the record of each activity in the supply chain. This record is shareable, traceable, authentic, and legitimate. In this background, Kshetri (2021) conducted multiple case studies and assessed the environmental and social impacts of blockchain. Blockchain technology also uses diverse technologies such as IoT, QR codes, RFID tags, and satellite imagery (Kshetri, 2017). Cao et al. (2021) have conducted a study with a partnership of Australian agricultural processors and developed a mechanism of human–machine reconciles with an overall focus on traceability in the beef supply chain system. Different challenges faced by the pharmaceutical industry involve counterfeit and other operational issues. (A et al., 2021) worked on traceability problems of vaccines and developed a model based on blockchain and big data to track the handling of vaccine in cold storage in India. Digitalization has played an important role in the sustainable agriculture supply chain but there is limited research about the factors which motivate to adopt digital technologies (Davis, 1993). In this perspective, Saurabh and Dey (2021) identified some drivers which are the motivators to adopt blockchain. These drivers are price, trust, traceability, disintermediation, compliance, coordination, and control. Köhler and Pizzol (2020) conducted the six case studies on blockchain-based food supply chains and developed a framework for its assessment using components including the technique, organization knowledge, and product (Seawright and Gerring, 2008).

4.4 Case Studies Relevant to Economic Sustainability in the Blockchain-Based Supply Chain in Different Sectors

A blockchain-based system can reduce the intermediaries and need for centralized authority because it provides the transaction record, efficiency, and transparency (Pournader et al., 2019). The sustainability effects are linked to visibility and traceability in the supply chain. The articles related to the case studies in different sectors are listed in "**Table 4**."

1) The area of application of these case studies is supply chains of chemical, cargo, shipping, logistics, retail, aviation, textile, construction, automotive, trading, mineral, and oil sectors.
2) Some articles are conceptual based; however, different solution approaches used in some case studies are action research through case studies, quantitative research methodology, qualitative research methodology, and prototype development.
3) Some case studies are based on the development of Ethereum-based consortiums, algorithm based on small contract, simulation-based models, and operation research techniques.

4.5 Critical Success Factors, Barriers, and Challenges in Adoption of Blockchain for Economic Sustainability in the Supply Chain

Blockchain is continuously gaining the attention of researchers and practitioners, and it has a potential to bring breakthroughs in the entire supply chain (Kamble et al., 2018). Some case studies of blockchain in different supply chain fields including agriculture, food, health, and manufacturing sectors are discussed in previous sections. Improvement in sustainability includes different dimensions including transparency, traceability, visibility, efficiency, and green practices (Yadav et al., 2020). The adoption of this technology has not gained much acceptance for several years (Dutta et al., 2020). The barriers and challenges for adoption of blockchain for an economically sustainable supply chain are critically examined, and its critical success factors are discussed. Details of relevant articles are given in "**Table 5**."

1) These challenges and barriers are in different areas of applications such as the agriculture and food sectors, pharmaceutical, manufacturing sector, maritime industry, fashion industry, small and medium enterprises, and local and global supply chains.
2) Most of the researchers have used the solution methodology for identification and ranking of challenges and barriers, which is the decision-making trial and evaluation

TABLE 4 | Case studies related to economic sustainability in the blockchain-based supply chain for different sectors.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Sikorski et al. (2017)	The objective of this study was to find the applications of blockchain in industry 4.0.	Process flowsheet models	Chemical industry	A longitudinal study is required for validation of the proposed model.
2.	Sundarakani et al. (2021)	A case study of different industries is undertaken to analyze the effects of blockchain adoption.	Action research	Cargo and chemical industry	Future research should employ the techniques of primary data collection.
3.	Yang, (2019)	The study is about the application of blockchain.	Quantitative methodology	Shipping industry	The research is limited to only one industry.
4.	Ahmad et al. (2021)	The authors have developed an architecture to highlight the components and participants to automate the logistics of ports.	Blockchain-based architectures	Logistics of ports	There is a need to expand the usage of developed architecture in other sectors.
5.	Min, (2019)	This article unveils the charisma of blockchain to increase resilience.	Conceptual research	Technology sector	It is a conceptual research study and requires a case study for its validation.
6.	Fosso Wamba et al. (2020)	The main aim is to validate the performance of a blockchain-based supply chain.	Quantitative research methodology	Technology sector	More attributes as moderators or mediators should be explored.
7.	Lahkani et al. (2020)	In this research, blockchain was incorporated into the B2B global supply chain.	Conceptual research	E-commerce sector	It is a conceptual research study and requires a case study for its validation.
8.	Xu et al. (2020)	The authors have discussed the different characteristics of blockchain such as transparency and traceability.	Case studies	Retail sector	Technical and regulatory constraints for the adoption of blockchain are not discussed.
9.	Sund et al. (2020)	The authors have developed a prototype to manage the supply chain efficiently.	Prototype development	Retail sector	The developed prototype is not optimized for best performance.
10.	Di Vaio and Varriale, (2020)	This research contributes by reviewing the literature about the implications of blockchain in operation management.	Airport collaborative decision making	Aviation industry in Italy	Future studies must also take into account the other international airports.
11.	Ho et al. (2021)	This research brings a system for the accurate traceability of spare parts to improve the inventory management.	Blockchain-based system architecture	Aviation industry	The proposed architecture only focuses on information gathering and does not explain data analytics.
12.	Donghui Hu et al. (2021)	Researchers have proposed a blockchain-based system for the data sharing.	Development of data trading platform	Trading sector	Empirical validation of this architecture is required.
13.	Agrawal et al. (2021)	A framework is proposed for the traceability of organic cotton through a mass-balancing validation mechanism.	Simulation-based model	Textile sector	Future research should be focussed on formulating a customized smart contract for different sectors.
14.	Kusi-Sarpong et al. (2022)	The study investigates the relation of blockchain, intellectual capital, and sustainable production.	Quantitative research methodology	Textile sector	Use of cross-sectional data is a further limitation of this study.
15.	Aslam et al. (2021)	The study is based on the sustainable supply chain practices in Pakistan for the oil industry.	Quantitative research methodology	Oil industry	The relationship between features of blockchain and supply chain practices should be empirically validated.
16.	Zhaojingang et al. (2020)	The authors have developed a framework based on blockchain. They have used an algorithm of smart contracts.	Development of algorithm	Construction industry	The concept of blockchain in the construction industry is in the early stage, and it should be further validated.
17.	Calvão and Archer, (2021)	The authors have conducted qualitative research from different people of the mineral supply chain.	Qualitative research methodology	Mineral supply chain	The benefits of digitalization should be the quantified mineral supply chain.
18.	Kuhn et al. (2021)	An architecture is proposed to gain transparency in the automotive supply chain.	Prototypical development	Automotive sector	The concept should be used in manufacturing to automate the tracing system.
19.	Kamble et al. (2021b)	The main objective of this study is to investigate the effect of the information-enabled supply chain on its sustainable performance.	Quantitative research methodology	Automotive sector	The study emphasizes only on economic aspects of sustainability.
20.	Gopalakrishnan et al. (2021)	This study is about the application of blockchain in solid waste management.	Operation research	Solid waste management	Cost aspects in this model of a supply chain are not considered.

laboratory (DEMATEL); the other methodologies used are the analytic hierarchical process, a fishbone diagram and Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) analysis, intuitionistic fuzzy AHP (multi-criteria decision making), fuzzy VIKOR, qualitative research methodology, and quantitative research methodology "interpretive structural modeling (ISM)."

3) Most of the identified barriers can be categorized into technical, organizational, and environmental barriers.

Blockchain is a revolutionary technology that will transform the entire supply chain, but there are many challenges and barriers in its implementation. In this context, Farooque et al. (2020) have collected the data from three organizations of China

TABLE 5 | Article list about different challenges in adoption of blockchain for an economically sustainable supply chain.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Kamble et al. (2020)	Authors have identified the enablers of blockchain.	Decision-making trial and evaluation laboratory	Agriculture and food sector	Future studies should include the cause-and-effect diagram for these enablers.
2.	Tayal et al. (2021)	In this article, a total of nine critical success factors are identified for the food supply chain.	Quantitative research methodology	Agriculture and food sector	A limited number of critical success factors are considered.
3.	Alharthi et al. (2020)	The main objective of this article is to evaluate the role of blockchain for the pharmaceutical industry.	Conceptual model	Pharmaceutical industry	The research is KSA-based and it has considered only three health providers.
4.	Nayak et al. (2019)	In this article, different success factors for adoption of blockchain for the green supply chain are identified.	"Interpretive structural modeling (ISM)"	Small and medium enterprises	These identified success factors are for the developing country India and cannot be generalized.
5.	Lohmer and Lasch, (2020)	The authors have conducted semi-structured interviews from experts of the industry to analyze the barriers during the adoption of blockchain.	Qualitative research methodology	Manufacturing sector	A comprehensive study is required on identified barriers.
6.	Farooque et al. (2020)	In this article, researchers have prioritized the barriers of blockchain adoption.	Fuzzy decision-making trial and evaluation	Manufacturing sector	Data are gathered only from three China-based organizations.
7.	Zhou et al. (2020)	The researchers have conducted a case study in the Singapore's maritime industry to identify critical success factors in the adoption of the blockchain technology.	Analytic hierarchical process, a fishbone diagram, and PESTLE analysis	Maritime industry	Their study is limited to the Singapore maritime industry.
8.	Ar et al. (2020)	This research is a framework that guides the decision makers for the adoption of blockchain in logistics.	Intuitionistic fuzzy AHP and fuzzy VIKOR	Large-scale logistics company	A more comprehensive study is required to consider all the required criteria for blockchain adoption.
9.	Caldarelli et al. (2021)	The main objective of this article is to identify different barriers in adoption of blockchain for a sustainable fashion supply chain.	Qualitative research methodology	Fashion industry	There should be some case studies based on quantitative studies to address the gaps in research.
10.	Saberi et al. (2018)	In this article, blockchain and smart contracts are examined.	Conceptual research	Supply chain management	Research is more focused on economic sustainability only.
11.	Yadav and Singh, (2020a)	The authors have identified critical successful factors.	Quantitative research methodology	Supply chain management	Data are collected from 195 respondents only, and the study has considered only 12 critical factors.
12.	Hastig and Sodhi, (2020)	Critical success factors for the implementation of blockchain are companies' capabilities, technical maturity, and governance.	Descriptive research	Supply chain management	Research is on a descriptive base and requires empirical validation.
13.	Ghode et al. (2020)	The authors identified different challenges for the implementation of blockchain.	Quantitative research methodology	Supply chain management	The research considered the participation of only five researchers and practitioners.
14.	Kouhizadeh et al. (2021)	This article presents a comprehensive overview of barriers for adoption of blockchain.	Decision-making trial and evaluation laboratory	Supply chain management	Interdependencies of sub-factors of these barriers need to be explored.
15.	Bischoff and Seuring, (2021)	Authors have presented a summary of barriers in the implementation of traceability systems.	Conceptual research	Supply chain management	The research is conceptual-based and not empirically validated.

about the experience of blockchain implementation. Their findings were that technological immaturity, poor organizational policies, and lack of government regulations are the main barriers. Saberi et al. (2018) examined the applications of blockchain in the context of sustainability. The important part of this critical examination is that how blockchain can overcome the barriers during its adoption. These barriers are categorized as intraorganizational, interorganizational, technical, and external barriers. Alharthi et al. (2020) explored the challenges in the adoption of blockchain for the pharmaceutical industry. The main issues found are lack of integration of this technology in the health system, lack of coordination among stakeholders, and poor demand forecasting of medicines (Zhou et al., 2020). Data were gathered from the 30 maritime professionals, and the analytical hierarchical process ("AHP") (and PESTLE analysis were applied to identify critical success factors.

The future work should be based on the development of a model or framework which considers all dimensions of sustainability including social, economic, and environmental perspectives. The model should be empirically validated for multiple sectors to draw a generalized conclusion, and all the benefits should be quantitatively measured. These frameworks and architecture should consider the other technologies which will be integrated with blockchain for data collection such as the Internet of Things, QR codes, RFID, and artificial intelligence.

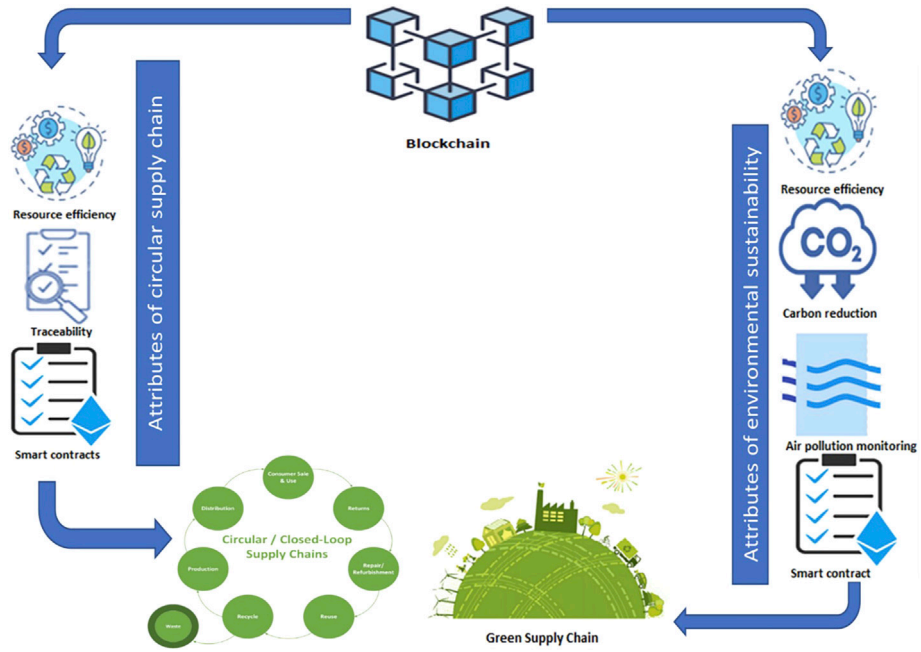

FIGURE 4 | Conceptual framework of transformation of the supply chain to the green/circular supply chain.

TABLE 6 | Models and frameworks related to the blockchain-based green/circular supply chain.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Casado-Varaa et al. (2018)	In this article, the author proposes a model of the supply chain.	Conceptual framework	Agriculture and food sector	In their model, they did not perform any economic evaluation.
2.	Bai et al. (2021)	This article proposes a framework of the green supply chain, which is based on a non-cooperative game.	Bayesian formula	Agriculture and food sector	The research is simulation-based and did not provide validation.
3.	Manupati et al. (2019)	The main aim of the research is to develop a blockchain-based model, with the main purpose to monitor the performance of the supply chain.	Mixed integer non-linear programming	Technology sector	The proposed model should be validated in different sectors such as hospitals, railways, and education.
4.	Treiblmaier, (2019)	This article is a framework about the integration of the physical internet and blockchain.	Conceptual framework	Technology sector	The effects of the blockchain technology for the triple bottom line should be quantified and measured.
5.	Bill Wang et al. (2020)	This article presents a system architecture of a circular supply chain integrated with blockchain for the fast fashion industry.	Conceptual architecture	Fashion industry	The input data should be obtained from multiple stakeholders.
6.	Tan et al. (2020)	The main objective of this article is to develop a green logistics-based framework integrated with blockchain.	Conceptual framework	Logistics	There is also a need to assess the risks while adopting the blockchain.
7	Centobelli et al. (2021)	The article suggests a framework called integrated Triple Retry to design the circular supply chain.	Conceptual framework	Waste management	It is a conceptual framework and requires validation.

5 BLOCKCHAIN-BASED CIRCULAR/ GREEN SUPPLY CHAIN MANAGEMENT

A sustainable supply chain is the flow of resources and information from supplier to end customer while considering the financial, societal, and environmental performances (Chen et al., 2014). The firms are focusing to increase the technical capabilities without affecting the triple bottom-line (Casino et al., 2019). Blockchain is used in different countries to control carbon generation efficiently. The conceptual model for the blockchain-based green supply chain or circular supply chain is shown in **Figure 4**. The two concepts discussed in this model are to form the circular supply chain and green supply chain by using the blockchain technology. The model of the circular supply chain urges the producers and manufacturers to remake and reuse the discarded material to make it more economical and environmentally

TABLE 7 | Case studies for the blockchain-based green/circular supply chain.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Friedman and Ormiston, (2022)	The findings of authors reveal that blockchain can ensure traceability, sustainability, and fair food supply chain.	Qualitative research	Agriculture and food sector	The food supply chains are very diverse. The findings of this study cannot be generalized.
2.	Kouhizadeh and Sarkis, (2018)	The article enlists the core dimensions of blockchain for the green supply chain.	Conceptual research based on the case study	Green supply chain	Their research provides only a conceptual overview of blockchain and the green supply chain.
3.	Mastos et al. (2021)	The waste-to-energy concept is proposed, developed, and used in a case study for its evaluation.	ReSOLVE model (regenerate, share, optimize, loop, virtualize, and exchange)	Supply chain management	Future studies should also consider the monitoring of the effects of the circular supply chain on air pollution.
4.	Park and Li, (2021)	Authors conducted case studies to compute the effects of blockchain on triple bottom line of sustainability.	Case study	Supply chain	The impact of blockchain should be investigated from the lens of suppliers, customers, and distributors.
5.	Czachorowski et al. (2019)	The study is about the proposed methods for the effective utilization of the blockchain technology.	Conceptual research based on case study	Maritime industry	The research did not quantify the effects of blockchain on sustainability.
6.	Esmaeilian et al. (2020)	The authors summarized the literature on the industry from the perspective of a sustainable supply chain.	Conceptual research	Social manufacturing	Future studies should be based on the optimization of business strategies to achieve sustainable goals.
7.	Khan et al. (2021)	The research examines the effect of blockchain on sustainable practices in the supply chain.	Quantitative research	Manufacturing sector	A comprehensive cost/benefit analysis is required for the adoption of blockchain in different sectors.
8.	Ajwani-Ramchandani et al. (2021b)	In this article, multiple and in-depth case studies are conducted to analyze the effectiveness of blockchain.	Empirical validation through a case study	Packaging waste	The main research focus was on emerging economies only.
9.	Ajwani-Ramchandani et al. (2021a)	The main objective of this research is to develop a concept that how blockchain and the circular supply chain can be integrated into the framework of linear economy.	Qualitative research methodology	Solid waste management	Future studies must consider artificial intelligence along with blockchain to develop the framework of circular economy.
10.	Nandi et al. (2021)	In this article, the author provides insights to form a resilient, sustainable, and transparent supply chain affected by COVID-19.	Conceptual research based on case study	COVID-19	Future research should be based on multiple studies for the use of blockchain and circular economy.

sustainable. Different characteristics of blockchain such as traceability and smart contracts are useful for the monitoring, controlling, and reducing the carbon footprints during different stages of supply chain. The air pollution monitoring will be useful for the carbon reduction. Similarly smart contracts can be developed to impose the carbon tax policies. For example, blockchain is used in Northern Europe to motivate the people for financial rewards in exchange for depositing the recyclables' plastic bottles or cans. Proper traceability of products through blockchain and resource efficiency can be useful to develop the complete structure of the close loop supply chain.

5.1 Model Development, Framework, and Architecture Related to Blockchain-Based Green and Circular Supply Chains

Blockchain is an assurance of transparency and human rights. The research on blockchain for the environmentally sustainable supply chain is in an early phase, but it is evolving rapidly. A list of articles for different models, architecture, and frameworks by different researchers are given in "**Table 6**" and discussed in detail. The main features of these research articles are as follows:

1) These models and frameworks are developed in different sectors such as waste management, the fashion industry, and the food and agriculture sectors.
2) Some articles are conceptual-based; other methodologies used are Bayesian formula, mixed integer non-linear programming (MINLP) model, and mathematical modeling techniques.
3) The main theme of these frameworks is a green supply chain, circular supply chain, and carbon reduction policies through smart contracts, recycling, and rework.

The new emerging technology including blockchain and physical internet (PI) can improve the sustainability by restructuring the entire supply chain. Bai et al. (2021) presented a framework of the green supply chain, which is based on a non-cooperative game, and they designed a model which was based on the Bayesian formula. They evaluated their work through simulation on Python 3.5. Manupati et al. (2019) developed a model to optimize carbon emission levels and operational cost. The circular supply chain is a transition from disposal to reuse and is a step toward a sustainable economy. Wang B. et al. (2020) presented system architecture of a circular supply chain. Their study analyzed the

challenges related to sustainability. Casado-Varaa et al, (2018) proposed a new model of an agricultural supply chain using blockchain. They used the multi-agent system based on smart contracts. The main advantage of the model was that through blockchain, the traceability of all the stages is possible.

5.2 Case Studies and Theoretical Developments of Blockchain in the Green/ Circular Supply Chain

Sustainable practices are implemented by the firms to mitigate the negative environmental and social effects in their supply chain (Rejeb and Rejeb, 2020; Gupta et al., 2021). The development in sustainability is the opportunity for all the firms to redesign their supply chain. The integration of big data, blockchain, and artificial intelligence can improve the sustainability goals linked to traceability, security, environmental degradation, and social ethics. Case studies and theoretical developments for the green/circular supply chain are listed in "**Table 7**." The main features of these case studies are as follows:

1) The different areas of applications of these case studies are the maritime industry, packaging waste, solid waste, agriculture, forestry, and fisheries industries; one article is written based on the background of COVID-19.
2) Many research articles are based on conceptual models validated through case studies; however, one research article is based on the ReSOLVE model (regenerate, share, optimize, loop, virtualize, and exchange).
3) Most of the themes are about the circular supply chain, waste-to-energy concepts, packaging waste, and integration of IoT and RFID technologies with blockchain.

The concept is the circular economy is evolving in recent times, which focuses to transform the products into new products after their useful life. In this context, Mastos et al. (2021) developed the waste-to-energy model and validated it by three case studies of the wood waste supply chain in the paradigm of industry 4.0. The knowledge of circular economy is still very limited, although it is adopted in developing countries (Kalmykova et al., 2018). Ajwani-Ramchandani et al. (2021a) provided the concept that how blockchains can be used for social and environmental sustainability in a circular supply chain. Modern society is more focused on social and environmental aspects. In this perspective, Kouhizadeh and Sarkis (2018) discussed the core dimensions of blockchain including decentralization of the database, secured transaction, information transparency, and smart contracts (Leng et al., 2019). The maritime industry is producing environmental degradation rapidly. Czachorowski et al. (2019) presented the insights on blockchain in the maritime industry for the reduction of pollution. Packaging waste is the most critical problem, which is a barrier for the implementation of sustainable development programs (Dahlbo et al., 2018).

5.3 Critical Success Factors, Barriers, and Challenges of Blockchain for the Green/ Circular Supply Chain

The most important success factor of blockchain is the awareness of customers. If manufacturing becomes green, then the environmental friendly customer will prefer purchasing the product. In this section, the barriers and adoption of blockchain for green/circular supply chains are critically examined, and its critical success factors are discussed. Details of relevant articles are given in "**Table 8**."

1) One of these articles is from the procurement section, and it has used quantitative and qualitative research methodology to find the challenges during blockchain adoption.
2) The second article is from the manufacturing sector, and it has used the decision-making trial and evaluation laboratory "DEMATEL" method, which is used to evaluate the critical success factors.

There were many limitations in articles relevant to case studies and theoretical developments in the blockchain-based green supply chain/circular supply chain. One common problem among all these studies is that these studies were cross-sectional studies and were unable to completely assess the effects of blockchain in different industrial sectors. A longitudinal study is needed to evaluate the long-term impacts of this nascent technology. Similarly, most of the studies were for a specific sector in a specific region. The geographic location, culture, laws, and people can affect the results and conclusions drawn from these studies. Another observation is that most of the studies were qualitative, and interviews conducted were structured or semi-structured. More quantitative studies should be included to get some quantifiable results and effects for all the attributes.

6 BLOCKCHAIN-BASED SOCIAL SUSTAINABILITY IN THE SUPPLY CHAIN

One major issue in the global supply chain is to protect the rights of workers and to provide them with a safe environment. There are a lot of standards for their rights, but it is common to violate the rules and regulations even in reputable organizations. Blockchain provides a commitment to achieve social sustainability. The parameters to measure the social sustainability include regional development, the welfare of workers, humanitarian supply chain, animals' health, transparency, fraud mitigation, trust development, and food security. A list of articles about the impacts of blockchain on social sustainability and for the humanitarian supply chain is given in "**Table 9**." The conceptual framework is given in "**Figure 5**." The main areas discussed in this framework are social sustainability and social welfare. Social welfare also includes the humanitarian supply chain management. The different attributes of blockchain such as accountability, transparency, and traceability will be beneficial for the fraud

TABLE 8 | Article related to challenges and barriers in the blockchain-based green/circular supply chain.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Rane and Thakker, (2019)	This article is about to analyze the impacts of blockchain on the green supply chain.	Qualitative and quantitative research	Procurement section	There is a need to form regulatory authorities for blockchain implementation in developing countries.
2.	Rane et al. (2020)	Authors evaluated the critical factors for the success of the green supply chain.	Quantitative research	Manufacturing sectors	The results of the study are useful only for the automobile industry.
3.	Huang et al. (2022)	In this study, authors evaluated the critical success factors for the implementation of blockchain for green supply chain management.	Analytical hierarchy process	Supply chain management	The data are collected only from researchers. Experts from the industry should be part of the evaluation system in future work.

prevention and trust development of all stakeholders. Traceability of products will improve the safety of food. Similarly, effective tracing and tracking will lead toward the transparency in humanitarian supply chain management. Important points of these research articles are as follows

1) Some articles are relevant to humanitarian supply chain management, in which used solution approaches are quantitative research methodology (partial least squares structural equation modeling), fuzzy delphi and best–worst method, fuzzy decision-making trial and evaluation laboratory, intuitionistic fuzzy analytic network process, and fuzzy best–worst method.
2) The area of application of other articles includes the agriculture and food sector, dairy sector, small and medium enterprises, manufacturing sector, social media, the fashion industry, and global supply chain. The methodologies used in these articles are quantitative research methodology (ISM-DEMATEL), qualitative research methodology, mathematical modeling, and conceptual research.

Food safety is the main concern of the developing world. In this perspective, Yadav et al. (2020) have got the opinion of experts in the agriculture industry in India. Their finding revealed that government regulations and lack of trust are the main barriers for blockchain adoption. Benzidia et al. (2021) developed a conceptual model based on the ambidexterity theory of dynamic capability. The organization strategy of ambidexterity with a balanced approach of social and technological factors between suppliers and customers will enhance the capabilities of digitalization and innovation potential of the buyer, while considering the sustainable processes. Patil et al. (2020) identified 14 barriers for blockchain in the humanitarian supply chain. The identified barriers are organizational, technological, and financial. Blockchain can increase transparency, which is the need for a halal food value chain. In this perspective, Ali et al. (2021) explored that the supply chain of halal food can achieve sustainability through blockchain technology. The strategic fit in the supply chain and regulatory intervention are the enablers in the success of blockchain. Mangla et al. (2021) collected the data from the dairy farmers and evaluated the social impacts of the blockchain technology on farmers and communities using different parameters such as rural area development, food fraud, animals' health, food security, healthy food, and transparency.

Supply chains are very complex nowadays, and customer satisfaction is very challenging in this era of globalization. Most of the work is carried out for economic sustainability, and research for environmental and social sustainability is scarce. Most of the experts of the supply chain do not recognize the new technology, so their responses are not as reliable to be considered for further analysis. Future research should be based on the data from multiple sectors from multiple regions, so a comparative analysis may be performed to identify and prioritize the challenges and barriers for blockchain implementation.

7 PRACTICAL IMPLICATIONS

This extensive review will provide insights about recent advances at the interface of blockchain and the supply chain to all the managers, researchers, practitioners, and policy makers who are involved in the supply chain. Blockchain can revolutionize different industrial sectors such as banking and finance, health and medicine, retail, agriculture, and logistics. The review is focused on different models' development, conceptual frameworks, and case studies about the implementation of blockchain. This research is useful by summarizing all the latest developments of blockchain and its effects on the sustainability of the supply chain for various sectors including agri-food, pharmaceuticals, manufacturing, automobiles, aviation, and many other national and international companies. Different attributes of blockchain are evaluated in this article, which include fraud mitigation, workers' welfare, animal health, food security, transparency, traceability, and resilient supply chain. It also sheds light on the social aspects of blockchain such as food safety, trustful collaboration, humanitarian logistics, and social welfare. Firms will be able to improve their strategies and policies using blockchain to broaden their eco-friendly practices, sustainable consumption of energy and natural resources,

TABLE 9 | Article related to blockchain use for social sustainability in the supply chain and humanitarian supply chain.

Sr	Author	Objective	Solution approach	Area of application	Limitation and future research direction
1.	Sander et al. (2018)	The objective of the article is to evaluate the acceptance of blockchain as a traceability system in the meat supply chain.	Quantitative research methodology	Agriculture and food sector	Future research should be based on a more complicated network of the supply chain.
2.	Yadav et al. (2020)	The authors have investigated the barriers in implementation of blockchain in the agriculture supply chain in India.	Quantitative research methodology	Agriculture and food sector	The study is based on a developing country. The social and cultural values of developed countries are different.
3.	Ali et al. (2021)	This article presents sustainable framework for the blockchain-based supply chain of halal food.	Qualitative research methodology	Agriculture and food sector	Future research should be based on the identification of challenges in the complex supply chain.
4.	Mangla et al. (2021)	This article evaluates and assesses the impacts of blockchain, fraud mitigation, welfare, animal health, food security, and transparency.	System dynamics modeling	Dairy sector	Different optimization models should be used to minimize the losses in the supply chain.
5.	Pazaitis et al. (2017)	The research exploits the potential of blockchain to facilitate the social sharing dynamics.	Conceptual framework	Sharing economy	The study is only on the theoretical background.
6.	Patil et al. (2020)	Authors have identified 14 barriers of blockchain for humanitarian supply chain management.	Fuzzy best–worst method	Humanitarian supply chain	Interrelation between different barriers should be explored.
7.	Queiroz et al. (2020)	Authors developed a model about the social influence on blockchain adoption and empirically validated it by Brazilian professionals.	Partial least squares structural equation	Humanitarian supply chain	It is difficult to present a comparison of different countries for implementation challenges of blockchain.
8.	Dubey et al. (2020)	Authors explored the effect of collaboration between all actors of disaster relief operations.	Fuzzy best–worst method	Humanitarian supply chain	Future research must include the interaction effect of organizational culture.
9.	Sahebi et al. (2020)	The authors identified barriers for blockchain adoption in the humanitarian supply chain.	Fuzzy delphi and best–worst method	Humanitarian supply chain	Lack of published data in the domain of blockchain and the humanitarian supply chain are the limitations of this study.
10.	Ozdemir et al. (2020)	This study aims to analyze the role of blockchain in mitigating the effects of barriers in the humanitarian supply chain.	Intuitionistic fuzzy analytic network	Humanitarian supply chain management	The sample size of data is very small.
11.	Wong et al. (2020)	The objective of this study is to investigate the impacts of top management participation, competitive pressure, market dynamics, and regulatory issues on the adoption of blockchain.	Quantitative research methodology "PLS-ANN"	Small and medium enterprises	The research is based on Malaysian companies, and future studies should include a cross-country evaluation.
12.	Kopyto et al. (2020)	The authors used the delphi method to get judgments from experts to analyze the influence of blockchain on societal, technical, and economic aspects of a supply chain.	Delphi method	Small and medium enterprises	The research is based on the qualitative study only.
13.	Benzidia et al. (2021)	The study is about the social effect of blockchain adoption on the relationship between the supplier and buyer.	Quantitative research methodology	Manufacturing sector	Research must be extended longitudinally by the involvement of more stakeholders.
14.	Queiroz and Fosso Wamba, (2019)	This study helps to understand the individual behavior on blockchain adoption in the supply chain in the United states and India.	Partial least squares structural equation modeling	Logistics	The developed construct does not consider the effort expectancy and unified theory of acceptance and the use of technology.
15.	Venkatesh et al. (2020)	In this article, system architecture is developed by the integration of big data, blockchain, and Internet of Things.	Conceptual architecture development	Process flow industries	Detailed research is required for challenges involved in the adoption of blockchain in different industries.
16.	Choi et al. (2020)	This article explores how blockchain can improve the transparency and trust of social media analytics.	Conceptual research	Social media	A multi-methodological approach can be used for research methodology.
17.	Nikolakis et al. (2018)	This article develops a verifiable framework to explain that blockchain can increase social sustainability.	Conceptual framework	Global value chains	The governance mechanism of information handling is still a big question in the adoption of blockchain.
18.	Choi and Luo, (2019)	A theoretical model is established about the effect of poor-quality data on sustainability of supply chain operations.	Operations research	Fashion industry	Future model should be price-dependent for realistic results.

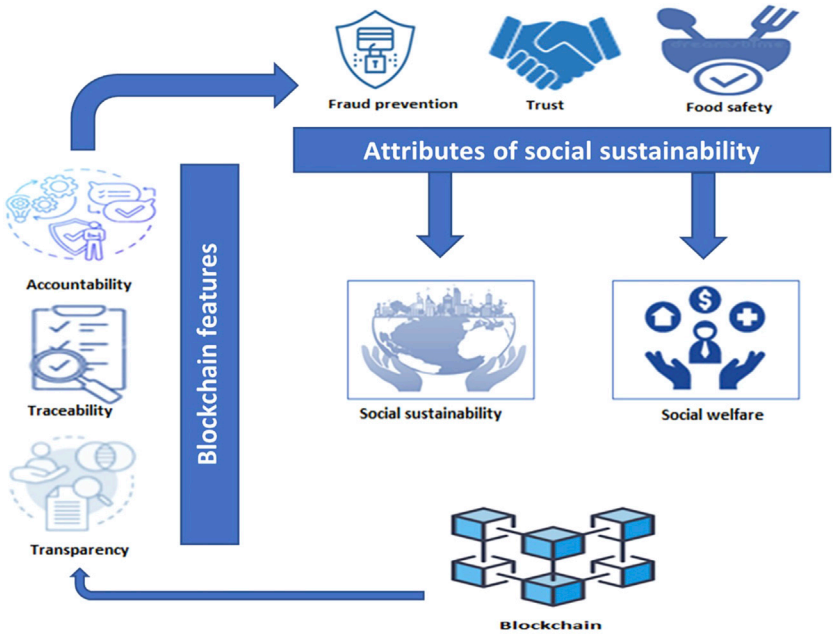

FIGURE 5 | Conceptual framework of transformation of the supply chain to attain social sustainability through blockchain.

and social vitality. Blockchain can foster the green supply chain by the traceability of products in an effective way and by monitoring the environmental compliance throughout the entire supply chain. Through efficient tracing, it will improve energy wastage and resource consumption. Finally, it will be helpful in transaction cost reduction through smart contracts and will increase the accuracy, speed, and efficiency of the supply chain.

8 CONCLUSION

After conducting the extensive literature review, it is being concluded that the supply chain has entered the era of blockchain and big data, and these technologies have great potential to revolutionize the entire network. The research was categorized into three domains. In the first category, blockchain and economic sustainability through different attributes of blockchain such as traceability, transparency, decentralization, visibility, smart contracts, accountability, immutability, and cybersecurity were evaluated through relevant literature studies. In the second category, the role of blockchain for the circular and green supply chains was assessed through a review of relevant articles. The benefits of blockchain in the humanitarian supply chain and its social aspects through trust development, fraud prevention, and food safety were critically examined in the third category. Different constructive characteristics of blockchain provide resilience, mutual trust, fraud mitigation, social welfare, and risk mitigation in the supply chain.

However, the scope of the present study is very broad, as it not only covers the triple bottom-line aspects of sustainability but it also lists the articles relevant to the humanitarian supply chain. Still, the study has limitations such as the research is conducted only from sustainability perspective and other aspects of supply chain such as resilience, agility, and robustness are not the scope of this study. The articles were selected only from Scopus-indexed journals, and some important information sources such as book chapters were neglected. Blockchain has a capability for the traceable, authentic, and reliable information flow using the smart contract, but the main question is still unanswered that is blockchain a real disruptive technology for social innovation or is it just an incremental technology that has very low strategic significance in supply chain sustainability. At present, several countries have adopted the blockchain technology in several sectors. Developed countries such as the United States and Japan are among the top countries for the acceptance and implementation of blockchain. Many African and Asian countries are also part of leading countries in blockchain adoption. In developing countries, blockchain adoption and green practices in procurement and the supply chain are at a very early stage, and there is a need to develop regulatory authorities at the government level to implement these practices. The effective use of the blockchain technology in developing countries with focused improvements will not only strengthen the economic aspects of the supply chain but will also improve its performance to comply with the environmental regulations and social aspects.

Future research direction in perspective of developmental research should be a joint function of blockchain with big data, life cycle assessment techniques, Internet of Things, and RFID. Future research should consider the limitations of blockchain in information handling, governance framework, and workability of smart contracts. Many

unaddressed questions should be explored, for example, what non-technological aspects such as company regulations, culture, and social acceptance will impact the adoption of blockchain? The basic lesson learned from the COVID-19 crisis is to manage the resilience and risk. It should be investigated that how blockchain will affect the cost, risks, and uncertainties during the operation and disruption. Future research should also consider the government's role in the adoption of blockchain. Overall, this article will provide an opportunity to academicians and researchers, for the complete understanding of the blockchain-based supply chain in paradigm of triple bottom-line aspects.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Each author contributed to the literature review, analysis, and to the writing of the manuscript. MAM (1st author) conceptualized and drafted the manuscript. AH, TM, and MH were the research supervisors and provided guidance for the collection of relevant articles. CS and AQ helped in developing frameworks, while MS, MAM (8th author), and SI contributed to the graphical abstract and figures.

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