

Sustainable supply chains using blockchain technology: A literature review

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Abstract

Responsible business practices are clearly necessary due to the growing complexity and globalization of today's supply networks. In order to learn how blockchain technology could improve supply chain sustainability, this literature review is being carried out. In order to adopt blockchain for sustainable supply chain management, it is necessary to synthesize current research, identify important trends, and assess the pros and cons of doing so. We made use of a systematic strategy by collecting appropriate peer-reviewed publications from leading scholarly databases such as Scopus and Web of Science. We then critically examine the selected publications to investigate themes, advantages, disadvantages, and potential future research directions about blockchain adoption. Through this review, we synthesize evidence supporting blockchain's enhanced accountability, traceability, and transparency, and weaknesses and potential future research areas. Blockchain technology has the potential to enhance supply chain accountability, traceability, and transparency, as the analysis indicates. In overcoming implementation challenges, subsequent research needs to be aimed at developing blockchain industry standards and solutions to scalability, as noted. Managers and executives looking to enhance their supply chains' sustainability performance through the use of blockchain will highly benefit from this review.

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1. Introduction

With the growing complexity and geographical diversification of operations in contemporary supply chains, it is becoming more difficult to ensure sustainability for all operational activities [1]. Ethical and sustainable business practices are increasingly demanded by consumers, governments, and other interest groups. References [2], [3], [4] all reference blockchain technology as one of the solutions to supply chain responsibility, transparency, and traceability problems. Increasing dependence on computerized systems and the need for controlling data breaches and misuse are two other push factors towards applying blockchain technology to supply chains [5]. The application of blockchain technology in supply chains has been the focus of a myriad of research studies. The positive impact of blockchain technology on trust and transparency has been the focus of many research studies. As an example, blockchain technology has the potential to enhance supply chain trust through data openness and verification that data does not get tampered with, as identified by

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a study by [6], [7]. According to [8-11] are some of them in which the ability of blockchain to facilitate supply chain sustainability is suggested. The ability of blockchain technology to transform sustainability efforts and supply chain management has captured the world's interest, as evidenced by [8].

Emerging economy companies can be facilitated by blockchain technology, as [10] suggests, since it enhances transparency and enables product tracking in a better manner [2], [12], [13], both of which help towards better sustainability practices. Park and Li also found that blockchain technology impacts supply chain sustainability performance [14] and emphasizes supply chain contributions toward a sustainable world economy, and provides evidence of blockchain contributions to sustainability. As suggested in ref. [15], it has been discovered through studies that blockchain technology can help companies achieve their sustainability goals through the availability of open information regarding the social and environmental impacts of supply chain activities. Secure, untainted data storage and immutability are supported by blockchain, which is a decentralized distributed ledger technology [16], [4]. According to [17], [13] established that blockchain technology is applicable to the supply chain for tracking the movement of data and products from source to destination.

As claimed by [3], [1], this enables proving of the product origin, storage condition, and adherence to sustainability. Blockchain technology enables companies to have their transactions recorded securely and traceably, which facilitates tracking of the product and data along the supply chain [18], [12], [19]. Blockchain technology makes the supply chain more accurate, transparent, and trustworthy tracking possible since it is decentralized, and once information is written, it cannot be altered. Without the threat of data tampering, blockchain immutably and openly seals all transactions, enabling all parties to monitor raw materials from source to product [20-22]. According to [10], [23] confirm that immutability and self-documentation of all the transactions and updates make it more transparent and eradicate fraud or error risks.

Less human interaction is required, and more efficiency with blockchain smart contracts that can make transactions and ensure compliance with common standards [24], [20]. In a bid to understand how blockchain might be utilized to render supply chains more environmentally friendly, we navigated what already exists in the literature. We examined both the advantages and disadvantages of blockchain usage, outlined leading areas of research, and made recommendations for future studies. First, studies on the topic are scattered across numerous sources, and the field overall is evolving rapidly [22]. This assessment collects all data published on the topic and gives an overview of it. This assessment identifies knowledge gaps and research directions through the literature review. For example, as suggested by [24], the review can point towards a deficiency of sufficient theoretical frameworks that address environmental, social, and economic dimensions of sustainability in an integrated manner. It can also state the impact of blockchain technology when integrated with other technologies, such as the Internet of Things and big data analytics. Such identification of gaps gives researchers a chance to focus on the most important issues. This analysis also gives a better insight into whether blockchain can lead to supply chain sustainability and the challenges of using it [1].

Among the listed are assessments of the following strengths and weaknesses of blockchain technology: fears of data privacy, scalability, and interoperability. The paper also presents theoretical foundations for assessing the capability of blockchain technology to deliver supply chain sustainability goals. Such persons can utilize the framework to design and implement blockchain solutions that work. Moreover, executives and managers who want to take advantage of blockchain technology to propel the advancement of sustainability performance in their supply chain can benefit from the literature review. They can make the optimal decision and maximize their return on investment if they have knowledge of what is possible through blockchain and what is not.

2. Research method

The aim of this research was to gain a comprehensive understanding of corporate perspectives regarding the integration of blockchain technology in sustainable supply chains and its possible evolution. The study was

conducted in two phases. In the initial selection conducted in July 2024, Tranfield's literature review methodology [25] was utilized, resulting in the analysis of 20 works related to sustainable supply chains and blockchain, sourced from the Google Scholar database. In June 2025, this research will be expanded in accordance with the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) formulated by [26]. This guideline has been utilized to execute a search strategy aimed at identifying relevant papers related to sustainable supply chains and blockchain technology. The information comes from Scopus and Web of Science and focuses on the terms "sustainable supply chain" and "blockchain technology". So, all studies that have these keywords will be included in the analysis. There are certain limits on the search: the years that matter are 2018 to 2025, and the categories of papers that can be found are "highly cited works," "review articles," and "open access."

Choosing the right field of study, Figure 1 below this explanation shows how to choose articles using the PRISMA-ScR approach. At first, 417 suitable research papers were located; however, 349 of them were not accepted after the title and abstract screening process. We omitted studies that did not focus on sustainable supply chains and blockchain technology. Numerous studies mentioned sustainable supply chains and blockchain technology in their abstracts as nascent technical advantages; however, they lacked adequate rigor in performing thorough assessments on the subject. 68 studies were selected for thorough analysis, assessed as full-text articles. 5 bibliometric analysis studies have been released based on their nature. Eight publications are not available, and 31 additional papers do not cover the desired aspects connected to blockchain technology. Using this method, 24 studies were finally picked based on the PRISMA-ScR framework. The final selection, which included both phases, consisted of 44 studies. This scope review will cover the following important points: What is a sustainable supply chain, and what is blockchain technology? What benefits can be gained by using blockchain technology in an environmentally friendly supply chain? What problems come up when trying to use blockchain technology in supply chains that are good for the environment?

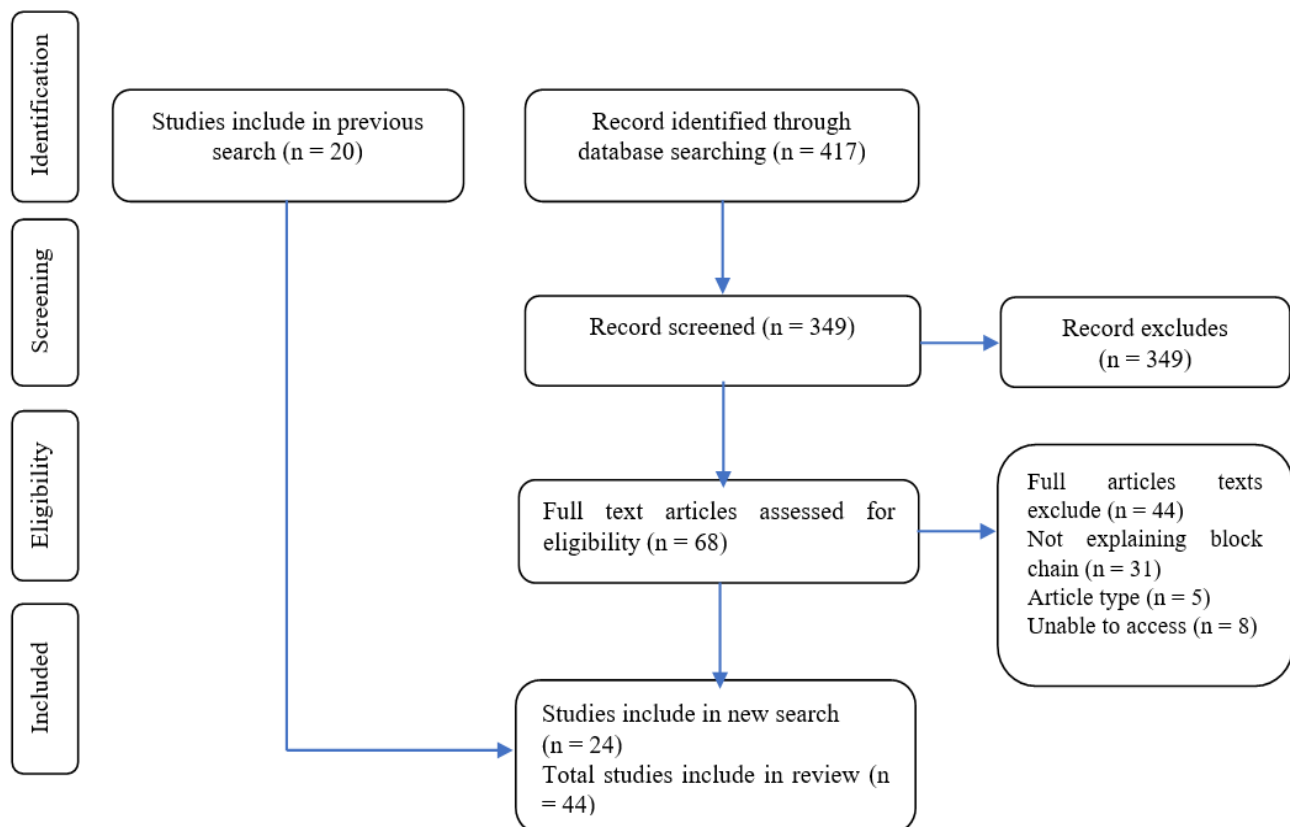


Figure 1. PRISMA Flowchart

3. Results and discussion

3.1. Main research trends

Increased research and academic attention towards blockchain technology have led to advancements in the area of sustainable supply chain management [22] at a very fast pace. There are certain self-evident directions of research that can be identified after a critical examination of the literature. Most of the research has been focused on how blockchain technology can enhance supply chain traceability and transparency [8], [4]. This involves tracking where they come from, what they're packed in, and if they meet sustainability standards. With this app, anyone can know if a product is actually sustainable and ethically, and environmentally sound. As stated by [22], blockchain technology can trace illegal fishing from the moment it is caught to the moment it gets to the consumer, and even enables safe online payments. The United Nations' sustainable development goals are promoted partly due to this. They continued to state that among the solutions that have been emerging to enhance traceability in supply chains are blockchain technologies. As per [13], blockchain technology has the capability to make supply chains more traceable and transparent through the creation of blocks with a timestamp for transactions, tracing the digital journey of the product, and enabling auditing of every single transaction. As per [20], one of the greatest strengths of blockchain technology for supply chain transparency is end-to-end traceability and product origin. The chronological and open documentation of every one of the transactions enables all the stakeholders involved to trace the movement of goods from their point of origin to where they reach. According to [5], this technology is capable of enabling individuals to determine whether a product is sustainable or not, and whether it is ethical and environmentally friendly or otherwise. Different studies have analyzed the uses of blockchain technology in different industries like food and beverages, pharmaceuticals, fashion, logistics, and supply chain [27], to mention a few.

Researchers [1] conclude that there exist various industries with various supply chain sustainability opportunities and issues. There is ongoing research aimed at creating blockchain solutions for all industries based on the unique needs of each industry. Saraswat et al. [27] conclude that blockchain technology is already applied in other various industries, including the food sector, pharmaceutical sector, agricultural sector, finance sector, education sector, retail sector, and healthcare sector. Together, they demonstrate how blockchain technology can transform different industries with enhanced transparency, security, and efficiency. The most feasible non-financial applications of blockchain are in energy, food and agriculture, and supply chains, as reported by [10]. In the initial stages of blockchain development, they can provide a palpable return on investment (ROI) and are most appropriate for blockchain technology, according to him. Examples of applying blockchain technology to sustainable supply chains are provided by [1]. A case in point is China's carbon asset market, by which companies can generate carbon assets more effectively.

Walmart has long struggled to make the food chain traceable and transparent, and, having tried and tested other less successful strategies, sees blockchain as the solution. Researchers [1] describe how varying industries have varying supply chain sustainability challenges and opportunities. Researchers are developing blockchain solutions specific to the individual needs of each industry. While blockchain is gaining momentum in a wide range of industries, it is not uncommon for developers now to want to integrate it with other technologies like the IoT, AI, and big data analytics. Another major breakthrough is interoperability with other frontier technologies and blockchain.

This covers IoT, AI, and big data analysis. The supply chain gains from enhanced decision-making, enhanced analysis, and more accurate data collection due to this integration. Internet of Things (IoT) sensors can monitor product data (e.g., location, temperature, and humidity) in real-time and record it on the blockchain. Because proper storage conditions are the most critical in the pharmaceutical and food supply chain, it is of priceless use [4]. Smart contracts, as they have come to be called by [23], can easily be triggered through the coordination of the Internet of Things (IoT) and blockchain technology [28]. Such agreements can be drafted in a manner that they can make automatic payments based on set parameters, for instance, when payables to suppliers for the delivery of goods. Utilization of the Internet of Things (IoT) and blockchain technology

makes possible secure data storage, the possibility of making automatic payments, and tracking of commodities in real-time [28], [4].

This, in turn, enhances efficiency, transparency, and security. Besides the Internet of Things (IoT), artificial intelligence (AI) can scan blockchain information for inconsistencies or trends that would indicate supply chain issues (e.g., delay or forgery). AI can optimize operational efficiency, predict demand, and optimize delivery paths [4], [29]. According to [30] contend that blockchain has the ability to leverage AI's enhanced automation and predictive capabilities. The functioning, risks, and prospects of the supply chain can be analyzed better using the humongous amounts of data created by blockchain technology. Using big data analytics, companies can improve supply chain sustainability and improve decision-making in general. Besides, [30] also identifies big data analytics as an essential instrument for monitoring and examining supply chain data regarding social sustainability transparency.

By combining all these systems, we can have a supply chain that can react better to the needs of our customers and the evolving market. Although there are blockchain solutions that have combined IoT, applications of AI-based predictive analytics in supply chains are facilitated by blockchain and are still in the infancy stage, says [4]. As per [27], Internet of Things (IoT) and smart contracts are the ideal pair that is creating new fields of research. Blockchain technology, as per [22], is influencing supply chain operations and also acts as a growth driver for new business models and governance. More equitable and transparent business models are achievable due to the decentralization of blockchain, which also allows for more collaboration among stakeholders. Disruptions and new business models are likely in the era of blockchain technology, according to [22], since operational efficiency is influenced by alterations in the information structure of the service supply chain. They also highlight that DLT can prompt new business models and operations for both start-ups and major companies.

Through the elimination of uncertainty and inefficiency within the supply chain, the origins traceability can prove to be an asset. Blockchain has the ability to mold sustainable supply network chains, [1] concludes. Blockchain is a distributed ledger, an immutable record, an open, and community-owned database. They demonstrate that blockchain technology, which was born in China and today supports the carbon asset market, is able to enable companies to make carbon assets more efficiently. Legally, blockchain makes information more reliable and puts an end to cheating processes [22]. But in order for it to be a reality, good governance, as well as robust legal frameworks, are required.

They indicated that blockchain laws are still to be developed, but if they were to be developed, they would affect procedures for operation and manufacturing. Blockchain technology is a development that can potentially change the nature of European supply chains as a measure of making them transparent, traceable, and credible [20]. The value reallocation among stakeholders and the firm, management, and supply chain governance will have to be reconfigured due to this innovation. According to [31], [1], one of the main reasons that supply chains are moving to use blockchain is that it promotes sustainability. Sustainable business practices are increasingly becoming vital to businesses as they realize the need for these aspects to society and the environment, as well as to their long-term profitability.

Sustainable management practices are being made possible through supply chain integration by [32], since increasingly, businesses are integrating their suppliers within their sustainable practices. Reverse logistics, green supply chains, industrial symbiosis, closed-loop supply chain designs, sustainable supply chain cooperation and circularity, and other green strategies are all described by [33] as instruments that can enhance the efficiency of the supply chain. Openness in the supply chain is essential for sustainable supply chain management, as stated by [34]. This is because it enables us to realize how various aspects of sustainable supply chain management, such as ESG, can be beneficial to various stakeholders. For enhanced social and environmental risk management, meeting stakeholder demands, and creating long-term value, companies are able to leverage blockchain technology in order to drive supply chain transparency, traceability, and accountability.

3.2. Leveraging blockchain technology and its benefits

There are several promising benefits that can be reaped from the use of blockchain technology in green supply chains. [3], [4], [30] say that blockchain technology allows all supply chain stakeholders to gain from sharing real-time and accurate information about products and processes. Difficulty in verifying the legitimacy and origin of products, data fragmentation, and absence of real-time visibility are usual problems for supply chain systems, as cited by [20]. As a distributed tamper-proof ledger system, blockchain has proven to be a game-changer in enhancing supply chain transparency. Apart from this, as [22] states, blockchain technology has the potential to enhance the accuracy and transparency of product flow through the global supply chain.

The ability to track products from origin all the way to the end point is one of the ways that blockchain technology can enhance traceability and contribute to sustainability. Blockchain can facilitate the achievement of United Nations Sustainable Development Goals 14.1 to 14.5, according to [22], through, among other things, secure online payment and illegal fishing tracking from the capture point all the way to its final use by consumers. Researchers [1] recommended integrating RFID (Radio Frequency Identification) with blockchain technology in order to enhance traceability of the food supply chain.

The unalterable ledger created by blockchain technology allows for accountability of all the stakeholders in the supply chain [15]. As per [1], blockchain technology can be used for rendering the supply chain socially sustainable by creating irreversible and stable data. Blockchain technology will not enable governments, immoral entities, or individuals to unjustly take property, as information cannot be modified without legal authorization. Clerical activities within the supply chain can be automated by means of blockchain technology, and cost savings and improved efficiency [4]. Supply chain operation cost and efficiency may be enhanced with the application of blockchain technology, according to [15]. Blockchain technology simplifies processes, eliminates intermediaries, and automates transactions via smart contracts, which eradicate human supervision and fraud, and also simplifies administrative work.

In addition, as [8] posits, blockchain technology is also likely to make processes efficient by eliminating some of the intermediaries and unnecessary manual processes. Through the provision of a secure yet open platform for information sharing, blockchain technology makes it easy for there to be more trust among supply chain partners [2]. When viewing blockchain technology from the perspective of the supply chain, whose lack of trust heavily deters coordination, [22] listed "trust" as the biggest strength of the technology. Blockchain technology, thus, not only enhances efficiency in operations and reduces costs but also upholds ethical as well as environmentally conscious company practices.

3.3. Difficulties in using blockchain technology

There are a lot of obstacles to implementing blockchain in sustainable supply chains, despite all the benefits it brings. Small and medium-sized firms may find the deployment of blockchain to be quite costly [3]. Any company will find the shift from legacy supply chains to blockchain-based systems to be extremely difficult [4]. Businesses need to provide serious thought and preparation to the problems of training, change management, and technological limitations. Another issue that could prevent blockchain from being widely used and interoperable is the absence of industry standards for it [4]. Standardization and technological governance are emphasized by [34]. Companies should form collective action initiatives to establish norms, reconsider the responsibilities of specific industry participants, and create participatory governance systems, according to his exploratory study. It may be difficult for certain blockchain networks to process large numbers of transactions due to scalability problems [4]. The collaboration between IBM and Maersk for blockchain-based maritime container management was highlighted in [1]. Here, IBM brought up the possibility that billions of dollars may be saved if the containers were tagged with a more precise and trustworthy bill of lading. Though savings in the billions are suggested, the feasibility of full adoption is uncertain due to scaling difficulties. One of the biggest problems with blockchain implementations, according

to [8], [35], [36], is scalability. This is particularly true for Proof of Work consensus implementations, which commonly encounter bottlenecks and higher transaction fees as data volumes increase.

The potential invasion of privacy by blockchain technology has certain interested parties worried [4]. According to [7], [37], [38], participants in the supply chain may face new difficulties when it comes to exchanging data due to differing privacy policies about the use and distribution of information and data. Blockchain technology's immutability makes it imperative that the supply chain establish and enforce standards and procedures for the exchange of data. Regulations surrounding blockchain technology are in the process of being revised, and any such revisions may have an impact on how supply chains employ blockchain technology [33], [4], [17]. Distributed electronic ledgers can only deliver on their promise under well-established legal and governmental frameworks, as [39] demonstrates. True sustainability with blockchain-supported solutions necessitates a mental shift and the intentional establishment and enforcement of lofty, quantifiable goals. In order to overcome these hurdles and make the most of blockchain in sustainable supply chains, firms should address these issues carefully.

3.4. Possible paths for further study

To realize blockchain's potential to deliver green supply chains, future research could explore the barriers to its uptake. Blockchain industry standards would open the door to interoperability and uptake, which is only one of a number of promising areas for future research in this field. In his paper, [34] places emphasis on blockchain technology regulation and standards. Firms, he added, ought to embark on collective action initiatives to set standards for their industry. Secondly, blockchain networks need scaling solutions, which should be the central research agenda [40], [41]. Referring to [1], [42], scalability issues typically keep blockchain from being used completely, even with its ability to save billions of dollars in supply chain management. Therefore, as per overcoming barriers as well as maximizing transaction cost efficiency in contrast to increasing data, further research needs to be conducted. Third, data privacy for individuals in blockchain networks is an area to be researched in the future. Along with the openness of data that is intrinsic in blockchain technology [33], [43], [44] further recommend that there must be clear policy and rule-making for information trading across supply chain networks [45], [13].

Fourth, emerging business models employing blockchain technology to establish more sustainable supply chains are something to be explored in the future. Researchers [46-48] assert that blockchain is one of the likely solutions to mitigate carbon emissions in supply chains. Also, companies will make automatic transactions according to information disclosed with the creation of smart contracts [23], [19], which will result in more favorable outcomes. Fifth, empirical case studies need to be employed to investigate the impact of blockchain on the sustainability performance of supply chains. There would be a requirement for researchers to research pilot projects and case studies to observe what works and what does not when utilizing blockchain technology [49], [50]. Although there has been valuable work conducted on integrating blockchain with supply chain management (SCM) in past studies, there are knowledge gaps that must be met [10], [4], [22].

4. Conclusions

This review of the literature illustrates how blockchain technology innovation has the potential to change the supply chain's sustainability. Blockchain has the potential to make unparalleled improvements in the supply chain sector through increased accountability, transparency, and traceability, as never before. This entails improved supply chain mapping and tracking material conditions and reuse. While scalability, high initial cost of setup, and non-existence of well-established industry standards are some of the issues in adopting blockchain, a number of significant long-term advantages exist. There are a number of noteworthy findings in supply chain sustainability in this literature review, whereby blockchain, besides ensuring traceability and transparency, can also guarantee product quality and sustainability as blockchain increases accountability by providing permanent transaction records. Apart from that, blockchain is also able to automate processes,

enhance productivity, and reduce costs, ultimately certifying the effect of supply chain processes on the environment and society. Evidently, this goes a long way in applying blockchain towards achieving a sustainable supply chain. But then, there also has to be some consideration of certain factors like the criticality of scalability, particularly in sophisticated supply chains, the comparatively high deployment cost, and the non-existence of standard protocols, which may possibly be limiting to adoption on a large scale. Not just that, even the presence of fluctuating regulations and the maturity of blockchain itself can prove to be an impediment. Organizational capability, information infrastructure, technical capabilities, and compliance with the law are some other determinants of blockchain adoption.

For future studies to facilitate the optimization of blockchain potential, more work is needed to build scalable and inexpensive solutions and to set up industry standards to advance interoperability among blockchain platforms. Additional research is needed to learn about how blockchain technology affects social and environmental measures of supply chain sustainability. This involves more insight into how blockchain can enable equitable labor practices, sustainable sourcing of materials, and minimize greenhouse gas emissions. Issues of adoption also need to be addressed to make the implementation of blockchain simpler in green supply chains. Adoption studies on blockchain in developing nations are found to be beneficial. Lastly, we can create a stronger and more sustainable future supply chain that is also more responsible if we act now to solve these issues and realize the potential of blockchain technology. Blockchain's capability to follow products from inception to delivery guarantees quality and sustainability. With such a change, firms can offer lasting economic, social, and environmental value.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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