A review of sustainability concerns in the use of blockchain technology: Evidence from the agri-food and the pharmaceutical sectors

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Abstract. Blockchain is an evolving technology with promising applications in various sectors. The introduction of blockchain in the industry has the potential to provide a significant competitive advantage, even though it still is in the early stages of its adoption, particularly in supply chains. The implementation of blockchain technologies affects all the operational aspects of a production and supply chain system, including its sustainable performance. In these terms, there is a raising of concerns regarding the impact of the integration of blockchain on the economic viability of the organization, the total environmental footprint that results from its use, and the social matters regarding its control, safety assurance, and governance. The scope of this paper is to identify the implications of the integration of blockchain technologies in the industry concerning the three main pillars of sustainability.

1 Introduction

Blockchain technology offers a transparent and secure way to record and confirm transactions [1]. To guarantee data integrity and participant confidence, it makes use of consensus procedures, distributed ledgers, and cryptographic techniques [2]. A distributed technology like blockchain makes it possible for players in logistical chains to communicate directly with one another, doing away with the need for middlemen. It guarantees to enhance supply chain management in terms of things like price, quality, swiftness, dependability, risk mitigation, sustainability, and adaptability [3]. Blockchains come in a variety of forms, including consortium, private, and public. While private blockchains limit access to approved users, public blockchains are accessible to everyone. All users are able to see data on consortium blockchains, but only a select few are able to write to the blocks [4].

Beyond the financial sector, blockchain technology has demonstrated tremendous promise, notably in sectors like supply chain, energy, healthcare, food and agriculture [5]. These industries are excellent candidates for blockchain adoption and even at this early stage of growth are anticipated to produce measurable returns on investment. In particular, the Internet of Things (IoT) and other innovations are transforming supply chain management. Blockchain offers real-time tracking of items across the supply chain, providing improved visibility, by utilizing IoT apps and tracking technology like RFID tags, sensors, and GPS. The potential of blockchain to deliver a secure identity management solution for IoT applications, assuring accountability and enabling monitoring of activities, time, and location, is one standout benefit of the technology [6]. This capacity enables precise measurement and monitoring of supply chain operations, promoting supplier confidence and obviating the need for middlemen. Additionally, blockchain makes it possible to accurately verify product quality while it is being transported, which is essential for perishable products like refrigerated food [7]. Stakeholders can ensure customers of the authenticity and quality of a product by evaluating travel data to identify deviations from correct handling or storage conditions. This addresses issues like food smuggling, related health hazards, and income loss, while also boosting customer confidence and willingness to buy particular brands [1].

The importance of blockchain in fostering sustainable supply chain management has been highlighted in several studies. These studies look at various facets of blockchain adoption and how it affects supply chain sustainability [8]. There has been some research on the inter-organizational, intra-organizational, technical, and external impediments to the use of blockchain technology, emphasizing the value of blockchain for supply chain sustainability [9]. In other research, the potential benefits of blockchain in improving environmental sustainability and green supply chain management are the main topics of discussion, giving an outline of the potential benefits of blockchain for environmentally friendly supply chains [10].

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Numerous research investigating the effects of blockchain technology on supply chain management have been conducted. These studies cover a wide range of applications, such as the creation of a standardized methodology for designing non-finance use cases, the implementation of public blockchains for agricultural supply chains, the governance of drug supply chains using the Gcoin blockchain, the use of blockchain for risk analysis in global supply chain operations, and the traceability of wood using blockchain [11]. Various reviews have shown that the agri-food and pharmaceutical sectors have great potential in implementing blockchain technologies as a means to ensure their product integrity and quality, facilitating their traceability through all the stages in the supply chain [12]. Although in sectors such as the agri-food and pharmaceutical industry, the potential of blockchain application has been thoroughly investigated, the actual implementation of such technologies and their impact on their operation has not yet been examined. For these reasons, these two sectors have been selected as the focus areas for the current research. This paper aims to identify the implications of the integration of blockchain technologies in the industry, focusing on the sustainable aspect of their implementation.

2 Theoretical Background

Blockchain technologies have been proposed lately as a solution to a lot of operational concerns of the supply chain, which could enhance the creation of economically, environmentally, and socially sustainable systems. Sustainability is one of the major concerns of various sectors nowadays, such as the agri-food and pharmaceutical. The theoretical approach of blockchain technology in the agri-food and pharmaceutical sectors will be researched in order to determine the potential use of blockchain technology in these sectors. In order to approach the sustainable aspect of the implementation of such tools, it is also necessary to look into the relationship between blockchain and the enhancement of sustainable systems, as described in the literature.

2.1 Blockchain in the Agri-food Sector

The field of agricultural supply chain management seems to be benefiting greatly from the use of blockchain technology in addressing issues and enhancing many parts of supply chains. Information and communication technology (ICT) systems have been widely used in cold chain management, but their susceptibility to hacking has presented difficulties. Due to its decentralized and trustworthy network, which improves security and information integration among chain participants, blockchain technology is viewed as a solution. Blockchain may enhance traceability and monitoring of product temperatures in cold chains, maintaining product quality and customer health. This is done by connecting smart contracts with IoT sensors [13].

In order to improve transparency and traceability in the food supply chain and solve problems like contamination and a lack of responsibility, blockchain technology is regarded as being essential. Blockchain aims to minimize labour and maintain traceability, which saves expenses and food waste while replacing expensive and time-consuming traditional techniques for protecting the food supply chain [14]. Blockchain can also help all stakeholders engaged in the supply chain and deliver operational advantages across several industries. Cost savings, higher standards of quality, risk mitigation, and sustainability are all in line with its main goals.

The field of scientific study on blockchain technologies for the agri-food sector is continuously changing. To maintain supply chain traceability, studies have concentrated on permissioned blockchain systems and several Distributed Ledger Technologies (DLTs). Scalability issues continue to be a problem, and there are currently just a few experiments or pilot projects using blockchain technology to assure production conditions.

Overall, the use of blockchain technology seems to significantly enhance supply chain operations in fields including food traceability, and agri-food supply chain management, as it improves traceability, security, and transparency, lowers costs and risks, and encourages supply chain sustainability [13].

2.2 Blockchain in the Pharmaceutical Sector

The blockchain technology has the potential to improve the security and traceability of the medicine supply chain, according to the US Food and medicine Administration (FDA) [15]. With the help of Frank Yiannas, a specialist in traceability technologies, the FDA launched a pilot study in 2019 to investigate how to use blockchain technology to strengthen the US food supply [11]. By monitoring operations, identifying responsible parties, and enabling real-time access to information regarding product quality, blockchain technology can offer benefits in automating and controlling pharmaceutical cold chains. By continually monitoring product temperatures, it also makes data integration easier and guarantees resource efficiency. As a component of the healthcare supply chain, the pharmaceutical cold chain encompasses several parties and presents issues with temperature control, the dependability of the infrastructure, and a variety of approaches. IoT, RFID, and wireless sensor networks are just a few examples of the technologies that have been used to improve coordination and communication inside the cold chain [16]. Improving electronic health records and addressing difficulties with counterfeit goods are all addressed by integrating blockchain technology into the cold chain. The tracing features of blockchain are essential for assuring medication security and fostering confidence. Blockchain technology can help waste management in the pharmaceutical business by ensuring data privacy, compliance, cost effectiveness, and speed in trash collection and disposal. Papers have been replaced with electronic medical records, which are more

readily available, secure, and shareable. Blockchain can ensure data consistency and security in the pharmaceutical industry by providing a single source of truth, trustworthy verification procedures, and tamper-proof transactions. Drug monitoring, fraud elimination, and supply security can all be facilitated by the transparency and tamper-proof nature of blockchain. Blockchain has important implications for controlling the medication supply chain, cutting prices, and doing away with middlemen.

2.3. Integration of Sustainability Pillars in Blockchain Implementation

In order to develop sustainable operations in supply chains across multiple industries, blockchain technology seems to provide a number of advantages. Blockchain enables the tracking of sustainability performances, supplier development, and the elimination of intermediaries in terms of vendor selection and supplier development. Additionally, it aids in the monitoring of environmental effects brought on by upstream suppliers, improving vendor selection and fostering a healthier environment [17]. Blockchain makes service operations on trucks during the COVID-19 outbreak easier while promoting trust and openness [18].

Blockchain aids the adoption of sustainable logistics and checks sustainability performance in transportation. It also enables green marketing through traceable packaging [19]. Blockchain in reverse logistics enables the tracking of materials' whereabouts and the verification of recyclers' activities, improving closed-loop supply chain management and encouraging sustainability.

Smart contracts play a significant role in humanitarian relief by facilitating quicker, more transparent, and more affordable transactions, doing away with middlemen, and reducing corruption [20]. Blockchain also contributes to the fight against illicit fishing by assuring traceability and blocking the selling of goods that were obtained unlawfully. Through crowdsourcing responsibility, it may impose labor and environmental norms around the globe, bringing about social advantages.

By creating transparent relationships between parties, blockchain solves problems like food adulteration, food safety, and quality management in the context of supply chain sustainability and the circular economy. It promotes recycling, decreases waste, and improves product return management in reverse supply chains. Implementing blockchain along with big data improves agricultural processes, such as tracking soil nutrients, managing irrigation, and maintaining quality. It also improves the environmental effects of transportation while lowering carbon emissions [21].

Blockchain, when combined with IoT and crowdsourcing platforms, enhances information management systems, supply chain security, and provides consensus methods to increase supply chain agility and resilience. Enhancing supply chain data storage, transparency, protection, and dependability

through blockchain integration with IoT and RFID. Especially in the face of disruptions brought on by events like natural disasters and viral outbreaks, the adoption of digital platforms powered by blockchain, IoT, and cloud computing plays a crucial role in supply chain risk management and resilience strategies.

Examining at many organizational levels as well as taking cultural aspects, norms, and industrial environment into account is necessary for the implementation of blockchain in sustainable and ethical supply chains. Adoption roadblocks including issues with data ownership, privacy worries, and IT integration must be resolved. The study of closed-loop supply chains, the circular economy, and reverse logistics is expanding, with blockchain and IoT advancing "product return management" and best practices. Long-term advantages come from "Physical Internet" and green manufacturing, and the combination of complementary technologies with blockchain improves the efficacy of blockchain applications in supply chains, promoting social, environmental, and economic sustainability [17].

The implementation of blockchain technology seems to be a catalyst to the creation of more sustainable supply chain systems. In order to establish these arguments, we are investigating real-life implementation examples of such technologies in the sectors mentioned above, detecting the concerns arising during the implementation process and examining the impact of their use on the supply chain management, in terms of sustainability.

3 Methodology

Our primary aim is to detect the most widespread blockchain applications in the agri-food and pharmaceutical industries and the assessment of their adoption concerning their economic, environmental and social impact. For this reason, we conducted the following searches in Scopus Database:

"BLOCKCHAIN" AND "AGRI-FOOD"

"BLOCKCHAIN" AND "PHARMA"

"BLOCKCHAIN" AND "APPLICATION" AND/OR "AGRI-FOOD"

"BLOCKCHAIN" AND "APPLICATION" AND/OR "PHARMA"

The results of this search included both theoretical and case studies concerning the implementation of blockchain in these sectors. Excluding the theoretical reviews, we observed that the available literature on the real-life applications of blockchain is very restricted. Research articles may gain insight from using grey literature as a valuable resource. Grey literature is used for a variety of reasons [22, 23]. Studies having null or negative results that may not otherwise be communicated might give data not available in commercially published literature through grey literature, which serves as an essential venue. Additionally, including grey literature might lessen publication bias, improve the thoroughness and

timeliness of reviews, and promote a balanced assessment of the information that is already available. Finally, grey literature can document unpublished research as well as discoveries in specialized or developing fields of study. Grey literature may also be a great source of unprocessed data. Grey literature can be challenging to look for and find, and it may be a major obstacle to conducting a thorough search for data. However, a systematic review may benefit greatly from a well-planned grey literature search technique. For these reasons, we searched the «grey literature» in order to collect data on the level of implementation of these technologies in the industry, as well as the assessment of their economic, environmental and social impacts.

4 Results and Discussion

4.1. Blockchain technology adoption in agri-food and pharmaceutical sectors

Our search in the above-described literature resulted to the detection of the following blockchain technologies around which there has been research concerning their implementation in the industry.

4.1.1 Tradelens

TradeLens was a cooperative initiative between IBM and Maersk that aimed to digitize and streamline global supply chains. The platform was designed to solve challenges such as inconsistency in data sharing across supply chains and the amount of time-consuming manual operations that raise expenses and cause shipment delays1. The goal was to increase global commerce efficiency and security, which might have a beneficial impact on sustainability by decreasing waste and streamlining logistics. However, the platform had problems recruiting additional shipping companies and as a result, the project was abandoned [24]

4.1.2 FoodTrust

FoodTrust is a blockchain-enabled platform that provides consumers with detailed information on the provenance of food in order to increase transparency and trust in the food system [25]. FoodTrust is a global food network comprised of various enterprises interested in reaping the platform's benefits [1]. Carrefour, a French multinational retailer, was one of its early users. The company keeps data from a range of food goods, such as tomatoes, citrus fruits, infant milk, and mashed potatoes, on the blockchain-enabled platform. With 10 major food producers and distributors, including Driscoll's, Dole, Kroger, Golden State Foods, McCormick and Company, Nestle, McLane Company, Tyson Foods, Unilever, and Walmart, IBM launched the Blockchain FoodTrust initiative. The project received aid from the IBM Blockchain. Records for more than 1 million food products are stored on IBM Blockchain and Hyperledger Fabric. All parties have access to a distributed ledger of

information on the origin of food, its status in transit, and other details through the platform. It was proposed that the average cost of returning goods might be reduced by 80% [5].

4.1.3 EverLedger

The provenance of supply is confirmed using blockchain-based technology provided by Everledger. It was first employed for rough diamond cutting. The diamond industry makes use of a certificate system [4]. Another blockchain-based wine monitoring system has been developed by Everledger. The bottle's cork is fastened with an RFID tag from Everledger that detects tampering. Older wines can be identified by traits like the label's layout and the paper the producer used during the year it was said to have been produced. The information offered includes high-resolution images and details from the label, capsule, cork, and glass. Digital data that contains ownership and storage details is updated when the wine bottle moves through the supply chain. The bottle's digital identification may be linked to by retailers, warehouses, auction houses, and other selling platforms to confirm provenance. Authentication certificates can be made public for marketing purposes or kept private. Everledger's approach neglected to record details like bottle temperature. Even though some recent media suggest that the project has been abandoned owing to a lack of financing, there is no current information on Everledger's status [26].

4.1.3 MediLedger

The MediLedger Network is a blockchain-based network created exclusively for the life sciences and healthcare industries [27]. It was founded in 2019 by industry leaders and is managed by Chronicled, a technological firm that is constantly developing and improving the network. Since 2019, FDA welcomes this pilot project and the solutions it proposes in order to meet the 2023 requirements of the Drug Supply Chain and Security Act [28]. The MediLedger Network uses blockchain technology to align, implement regulations, and settle real-time transactions between vendors. It provides a variety of solutions, such as contract and refund management, product verification, and saleable return management. All of these solutions begin in working groups, where industry players develop protocols and business rules to regulate transactions and interactions among trade partners.

The technologies mentioned, are shortly presented to the following table.

Table 1. Blockchain technologies in agri-food and pharmaceutical industries.

Blockchain Technology	Description	Level of implementation	Current Status
Tradelens	Global Supply Chains	Medium	Abandoned

FoodTrust	Food Traceability	Medium	Active
EverLedger	Product Authentication	Medium	Deactivated
MediLedger	Health Supply Chain	Pilot	Active

4.2 Sustainability concerns on Blockchain adoption

The above observations of the status of blockchain implementation arise several concerns regarding the barriers met during the transition towards blockchain-based supply chains. Going through the related literature we have detected the main issues that emerge in the decision-making and implementation process of the mentioned blockchain technologies and their implication in supply chain sustainability.

One of the main barriers concerning the integration of blockchain technologies is cost [29]. Usually the cost of purchasing the equipment, as well as the cost of training that is needed in order to manage these systems cannot be easily afforded, especially by small-medium enterprises [1]. It takes an inordinate quantity of time, money, and human resources to develop and maintain a standard system for data transmission and storage. The continuing system changes also come with additional costs. Although the blockchain system may reduce this expense, future consumers may not completely understand the cost of creating and storing data via blockchain. Consequently, it is challenging to deploy technology without understanding its exact cost.

In the case of TradeLens, the cost of adoption was the main reason for being abandoned, even though its use initially promised reduction of cost in supply chains operation. This can be partially explained, as the implementation of blockchain technologies, as they are currently structured, consists of long-term investments, and cannot guarantee short-term profits. For this reason, there is a strong need for the implementation of a reliable decision-making system concerning the choice of the most appropriate blockchain system for each business [30]. In this way, the economic viability of the supply chain system is ensured.

The environmental contribution of blockchain technologies is one of the strongest arguments presented in order to invest in these technologies. For example, Everledger is making a substantial contribution to advancing the development of circular economy, especially in the battery business. This concept would allow batteries to be repurposed for energy storage after they approach the end of their useful life in a vehicle, which is often while they still have 70% to 80% of their capacity remaining. This not only cuts waste but also increases the practical value of these resources. FoodTrust initiative also focuses on the reduction of food losses and waste, contributing to the reduction of the environmental impact of the food sector. Even though there is a lot of research around the potentials of these blockchain technologies, their implementation has not been fully completed and, as a result, there are no

real data in order to cross-check this hypothesis. In addition, there has been a lot of concern around the emissions and, thus, the environmental impact of the use of blockchain technologies [10].

The social concerns around the use of blockchain are multiple. First of all, one of the main concerns is the governance of such systems. Local and national regulations frequently become impediments to blockchain innovations, therefore there is a rising need for government bodies to be involved in rule and regulatory compliance when building innovative blockchain-based solutions [17]. The lack of government regulations related to blockchain transactions, increases the uncertainty of the blockchain environment [3]. Furthermore, it is difficult for a single platform to provide the visibility required the procedure monitoring. To attain visibility, some type of method for accessing data across various platforms and their associated ecosystems will be necessary. This also raises governance issues such as how data can be accessed through the various platforms, how authentication and entry authority are possible to safeguard, issues related to motives for organizations to share data for CE monitoring purposes, and standards and blockchain interoperability [5]. Especially in the case of pharmaceutical sector and the use of MediLedger, experts in the highly regulated health industry are considering how decentralized models fit within the present legal framework and what revisions may be required to permit innovative methods [30].

Data integrity and protection is another societal problem that has emerged as a result of the use of blockchain technology. One argument is that since there is only one ledger, a traditional ledger is more susceptible to hacking and is therefore less safe than a blockchain. Additionally, a permissioned/private blockchain promotes confidence because all stakeholders have been given membership rights. Blockchain, however, was first created for an untrustworthy world. The additional costs associated with using blockchain are rendered unnecessary if there is sufficient confidence [11]. Information broadcast by one node may be read by all nodes in a system because, in the blockchain, all transactions are confirmed by all community members rather than a third party. This exposes the data to potential privacy and security risks.

In addition to this, product quality and safety should always be guaranteed, particularly in the case of supply chains for pharmaceutical and agri-food products. Fraud in these sectors is a major issue that blockchain argues to confront. A blockchain-based data system might encourage supply chain participants to submit data to it in ways in which data falsification does not happen. However, there is no guarantee that the data correlates to reality. Product provenance is a vital component of blockchain that includes product history, origin, and traceability. It is crucial to understand how to correctly and accurately convey product provenance information [31].

In order to achieve all these goals and adopt an integrated blockchain system, the alignment of all stakeholders is necessary [32]. In order to create a long

living system through blockchain implementation, all stakeholders should be willing to cooperate and share information and knowledge that could lead to the creation of a transparent way of operation. Taking into consideration that in the case of supply chain networks the stakeholders may come from different fields, this kind of cooperation should be continuously surveilled and audited, in order to ensure equality between all the parties involved [33]

5 Conclusions

Blockchain technologies have the potential to be implemented by various sectors, as they offer a lot of capabilities to the users, concerning supply chain operational systems. Especially in the case of agri-food and pharmaceutical supply chains, the use of blockchains seems to be very promising. The current implementation of blockchain technologies in these sectors is in an premature level. As a result, there are no real data in order to assess the sustainable outcome of the use of blockchain technologies. The barriers coming up in the progress of implementation vary, and are connected to economic, environmental and social issues. Therefore, the interconnection between blockchain implementation concerns and sustainability is apparent.

Not all three pillars of sustainable development are equally considered regarding blockchain. Most of the arguments enhancing the use of blockchain, are based on the future reduce of the total environmental impact. However, the environmental impact of the use of blockchain itself cannot be assessed until its application moves to the next level. The cost of implementing blockchain is one of the major reasons for abandoning blockchain use. As a result, blockchain technology does not appear to be viable when it come to industrial application. Even though the cost of maintaining such a system is high, the long-term profitability could also be assessed. On the social side, there are many barriers, mainly connected to trust, security, safety and quality issues. In order to overcome these barriers, there is a need for creating an integrated governance system to enclose the needs of blockchain operations.

As promising as blockchain may be according to the literature, its implementation in the real world seems to be blocked by various factors that were not predicted during the early stages of its development. The failure of several blockchain systems integration could be a field of research in order to detect the reasons of failure and modify the developing blockchain technologies in order to overcome these challenges.

The available literature for the implementation of blockchain in the industry is very limited. For this reason, we turned to the "grey literature" in order to find recent information on the implementation status of blockchain. Further research could be made, by using primary data from business which were involved in blockchain applications.

References

1. Z. Li, R.Y. Zhong, Z.G. Tian, H.N. Dai, A.V. Barenji, G.Q. Huang, Robot. Comput.-Integr. Manuf. **70**, 102124 (2021)

2. S. Bonnet, F. Teuteberg, Comput. Ind. **144**, 103789 (2023)

3. G. Balci, E. Surucu-Balci, Transp. Res. E Logist. Transp. Rev. **156**, 102539 (2021)

4. S. Tönnissen, F. Teuteberg, Int. J. Inf. Manag. **52**, 101953 (2020)

5. A. Kofos, J. Ubacht, B. Rukanova, G. Korevaar, N. Kouwenhoven, Y.H. Tan, J. Respons. Technol. **10**, 100026 (2022)

6. N. Kshetri, Int. J. Inf. Manag. **39**, 80–89 (2018)

7. S.M. Hosseini Bamakan, S. Ghasemzadeh Moghaddam, S. Dehghan Manshadi, J. Clean. Prod. **302**, 127021 (2021)

8. S. Saurabh, K. Dey, J. Clean. Prod. **284**, 124731 (2021)

9. A. Castiglione, L. Cimmino, M. Di Nardo, T. Murino, Comp. Ind. Eng. **180**, 109263 (2023)

10. M. Qin, C.W. Su, O.R. Lobonţ, M. Umar, Int. Rev. Econ. Financy **86**, 604–615 (2023)

11. M. Alles, G.L. Gray, Int. J. Account. Inf. Syst. **38**, 100465 (2020)

12. T. Dasaklis, T. Voutsinas, G. Tsoulfas, E. Casino, Sustainability **14**, 2439 (2022)

13. M. Martínez-Castañeda, C. Feijoo, Telecom. Pol. **47**, 102574 (2023)

14. N. Patelli, M. Mandrioli, J. Food Sci. **85**, 3670–3678 (2020)

15. R. Jafri, S. Singh, *Blockchain Applications for Healthcare Informatics*, 71–92 (Academic Press, 2022)

16. A. Carbone, D. Davcev, K. Mitreski, L. Kocarev, V. Stankovski (2018)

17. P. Dutta, T.M. Choi, S. Somani, R. Butala, Transp. Res. E Log. Transp. Rev. **142**, 102067 (2020)

18. M. Quayson, C. Bai, V. Osei, IEEE Eng. Manag. Rev. **48**, 104–110 (2020)

19. F. Calvão, M. Archer, Polit. Geog. **87**, 102381 (2021)

20. L. Batista, M. Bourlakis, P. Smart, R. Maull, Prod. Plann. Contr. **29**, 438–451 (2018)

21. L. Manning, Food Syst. Agric. Ind. 153–187 (2018)

22. K.M. Benzies, S. Premji, K.A. Hayden, K. Serrett, Worldviews Evid.-Bas. Nurs. **3**, 55–61 (2006)

23. Q. Mahood, D. Van Eerd, E. Irvin, Res. Synth. Meth. **5**, 221–234 (2014)

24. M. Jovanovic, N. Kostić, L.M. Sebastian, T. Sedej, Technolog. Forecast. Soc. Change **184**, 121981 (2022)

25. IBM, *IBM Supply Chain Intelligence Suite: Food Trust*

26. H. Partz, *Tencent-backed Everledger collapses amid lack of funding: Report*

27. V. Shcherbakov, G. Silkina, J. Open Innov. Technol. Mark. Complex. **7**, 54 (2021)

28. FDA, *MediLedger Pilot Project.pdf*

29. F. Lorenz-Meyer, V. Santos, Procedia Comput. Sci. **219**, 807–814 (2023)

30. M. Pisa, Innov. Technol. Govern. Global. **12**, 80–88 (2018)

31. F. Casino, V. Kanakaris, T.K. Dasaklis, S. Moschuris, S. Stachtiaris, M. Pagoni, N.P. Rachaniotis, Int. J. Prod. Res. **59**, 5758–5770 (2021)

32. M. Wever, N. Wognum, J. Trienekens, O Omta, Meat Sci. **84**, 228–237 (2010)

33. S.K. Arumugam, A.M. Sharma, *Lessons from COVID-19*, 61–94 (Academic Press, 2022)