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SURVEY

Blockchain in Agriculture: A PESTELS Analysis

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ABSTRACT Blockchain (BC) represents a disruptive technology that has been extensively used to ensure immutability of digital transactions. Starting as an underlying mechanism in the digital currency sector, it has been applicable in a wide range of sectors and application domains. Agriculture represents a sector of significance for overall sustainability challenges that is benefiting from digitalisation and technological evolution and the enforcement of Industry 4.0 paradigm shift towards precision agriculture. Introduction of Internet of Things, and Cyber-Physical Systems increase overall complexity, with Big Data analysis and Machine Learning technologies paving the way for innovative applications. BC appears to be a promising technology for agriculture introducing new mechanisms for tracing of products and overall agricultural Supply Chain management from the farm to the fork. The authors perform a review of 152 scientific works, providing a concise summary for each and extracting current challenges and open issues for the application of BC in agriculture. By synthesizing their findings, they perform a state of the art analysis along the PESTELS framework. A large number of challenges including technological ones, create big research potential for the evolution of the area.

INDEX TERMS Blockchain, agriculture, PESTELS, sustainability, supply-chain, challenges.

I. INTRODUCTION

United Nations (UN) 2030 Agenda for Sustainable Development [1], represents a plan of action for people, planet and prosperity, to address the major challenges facing humanity. Its 17 Sustainable Development Goals (SDGs), embodying the Agenda, set targets mandating the involvement of the entire Quadruple Helix stakeholders. At least two of the SDGs are related to the agricultural sector: SDG 1, focusing on the fight against poverty, and SDG 2, envisaging a world with zero hunger. Both address the challenge of Food Security identified as a critical element due to a combined mix of global population growth, urbanization trends, degradation of farmland, climate change induced risks, and food waste [2]. It is estimated that in order to guarantee food security, agricultural production should increase by 70 percent by 2050, exploiting technologies leading to Agriculture 4.0.

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The achievement of UN SDGs by 2030, mandates significant allocation of resources estimated to USD 2.5 trillion per year [3] before the COVID-19 pandemic. The pandemic has had a significant impact on SDGs [4] erasing some of the progress, slowing down their implementation, reallocating resources to immediate priority sectors.

Technological evolution and overall digitalization driving towards Agriculture 4.0 can act as enablers for a more sustainable and resilient agrifood sector and significantly contribute to the achievement of the UN SDGs. Cyber-Physical Systems (CPS) lie at the cross section of physical and digital worlds, and present a wide range of applications in different domains [5], [6] enabling what is known as Industry 4.0 [7], [8] paradigm shift. The applicability of such a CPS-enabled paradigm, based on deployed sensory and embedded systems infrastructure, generating Big Data to be utilized by Machine Learning (ML) and Artificial Intelligence (AI) algorithms to the end of providing advanced services and products, is wide covering almost every aspect of modern life and leading to

Society 5.0 [9], [10] model shift. Smart agriculture and food are among the application domains affected by this evolution.

Blockchain (BC) represents a disruptive technology [11] with applicability in different domains. Starting as the technology behind the development of the cryptocurrency Bitcoin [12], it is based on a distributed non-coordinated peer-to-peer network, that timestamps transactions by hashing them into a proof-of-work on-going chain. Alongside the wider technological evolution associated with the Industry 4.0 transition, BC technology can offer opportunities related to transaction security aspects.

The authors of the paper make a systematic review of recent works related to the application of BC technology in the agricultural and agrifood sector. The paper addresses the following research questions (RQ):

RQ1: What are the main challenges for the application of BC technology in agriculture?

RQ2: Are there any technological gaps with reference to the application of BC in agriculture?

The main contributions of the paper include (i) it applies the PESTELS framework reviewing existing works related to the application of BC technology in agriculture; (ii) it offers a new perspective in classifying challenges for the application of BC in agriculture seeing them from seven different aspects (Political, Economical, Social, Technological, Environmental, Legal and Security); (iii) it identifies technological gaps for the application of BC in agriculture and relevant lines of research.

The rest of the paper is structured as follows. Section II presents background knowledge on BC technology and an overview of its application in the agricultural sector. Section III elaborates on the methodology according to which the review was performed. Section IV presents and discusses the results, while Section V provides a conclusion.

II. BLOCKCHAIN TECHNOLOGY OVERVIEW

BC, as a technology, is well known to the general public mainly due to its use as an underlying mechanism to ensure the immutability of digital transactions in the form of digital currency called Bitcoin. While cryptocurrencies are the better known applications of BC technology, BC can and has been used in a wide variety of sectors and application domains ranging from the energy consumption sector to the tracing of products throughout their Supply-Chains (SCs) in the manufacturing and agricultural sectors.

In [13] a review of BC usage in different domains is presented. Top ten fields of BC application according to publication records include the Internet of Things (IoT), Energy, Healthcare, Finance, Resource Management, Government, Exchange, Transportation, Business Process Management and Rights Management. A more recent review [14] concludes that although financial management and security issues have been at the focus since 2015, use of BC in education has become central research theme in 2021, with domains like healthcare, IoT, and government applications also growing in popularity.

BC is a system that relies on a peer-to peer network of nodes that behave as equals to each other, without the need for a system of fixed servers. The network nodes, which correspond to the network participants, aim to update and maintain the stability of a public database (ledger) called the Blockchain. This Blockchain records the transactions between participants of the network. Each of the nodes acts as a client and server simultaneously allowing the exchange of information between the different computers in the network nodes. The system can be implemented over a public network such as the Internet.

The nodes of the network that verify these transactions are called miners. Miners formalize these transactions and receive some kind of compensation (an amount of coins in the case of bitcoin) as a reward for their activity. The challenge of this new paradigm would be to avoid the problem of double spending. Double-spending is related to the possibility that an electronic file could be duplicated and, in the absence of a trusted third party who can verify whether a transaction has taken place, lead to fraudulent transactions where users could duplicate said transactions. This challenge is addressed, initially, by the proof-of-work protocol where, all nodes would have a copy of the hash that refers to a given transaction. Proof of Work (PoW) is a decentralized consensus mechanism that requires members of a network to expend effort solving an arbitrary mathematical puzzle to prevent anybody from gaming the transaction system. Once the information is validated by the network, any manipulation of that information would result in a detectable change in the hash of the BC blocks and would be immediately discarded. BC technology is enabling the development of different applications, based on the possibility of ensuring the exchange of information with the characteristic that the recipient of the information has the assurance that it is the original and has not been altered.

One of the criticisms of the use of technological advances such as the massive use of data, AI or Bitcoin, is that they need to consume large amounts of energy, pointing to the importance of the need for governments to make changes in their regulations. The United Nations Development Programme's Human Development Report 2020 cites literally: "Bitcoin energy use is alarming" [15]. All these technologies will have to make a major effort in the coming years to reduce their carbon footprint. Towards this direction, alternative consensus protocols have been developed, such as the Proof of Stake (PoS), that aim to displace the energy inefficient algorithms with processes that don't rely on who has the most processing power but rather on who has the most stakes on the correct validation of each transaction. Apart from PoW and PoS, there are various alternative consensus algorithms such as Proof of Activity (PoA), Delegated Proof of Stake (DPoS) and Practical Byzantine Fault Tolerance (PBFT) among others. A recent comparative analysis of the various BC consensus algorithms can be found in [16]. Following the expansion of BC applicability in different domains, its use in improving farm business operations and the agricultural sector in general is increasing [17]. BC technology can help improve resilience, flexibility and inclusiveness in the agricultural sector, which vulnerability has been exhibited during the COVID-19 pandemic crisis [18].

Through the years, there have been multitudes of BC technology frameworks, or BC platforms, in development. The most well known are the Bitcoin framework that is powering the first widely adopted cryptocurrency, Etherium, an open source framework that focuses on the secure execution and verification of application code called smart contract and Hyperledger Fabric, a project supported by the Linux Foundation that offers a modular enterprise-grade, distributed ledger platform with plug-and-play components such as consensus and privacy. From all those underlying technologies, the more popular in the agricultural sector are, according to a recent survey by Sendros et al. [19], Etherium and Hyperledger Fabric by a large margin. A big part of the literature does not mention a specific framework while some are proposing custom BC frameworks mainly based on the Etherium platform. Similarly, BC platforms can also be public or private. In public BCs, everyone can be part of the ledger as well as the consensus mechanism while private BCs usually belong to a single organization and are governed by it. They are also distinguished into permissioned and permissionless depending on whether there is a form of access control for the participation in the ledger and/or the consensus mechanism. According to the same survey, the majority of published approaches, for the agricultural sector, rely in private permissioned BCs with a close second in public permisionless BCs. As before, a big part of the literature does not mention a specific type of BC.

Various applications of BC have sprouted in the agricultural sector, as stakeholders are realising its considerable potential in facilitating trade and trust between multiple parties. Therefore, BC is the perfect candidate technology to support agrifood SC traceability, as more and more consumers prefer to know the provenance of the products they buy. Traceability is also needed by big retailers in order to better contain disease outbreaks and trace the contaminated products to their origin. According to Stranieri et al. [20] three BC use cases in poultry, lemon and orange SCs, have been developed by a big retailer to make data more transparent and increase product traceability. Another traceability use case by a big retailer to prevent contamination in pork chains across China is mentioned by Galvez et al. [21]. A further case of BC application is that of Grassroots Farmers Collective, a company which is utilizing BC to provide reliable information on the cooperative type of farm, and organic food production processes to end consumers [22]. Hang et al. [23] proposed an IoT BC-based fish farm platform to ensure agriculture data integrity. The designed platform aims to provide fish farmers with secure storage for preserving the large amounts of IoT agriculture data. Kramer et al. [24] presents use cases where BC has been applied in agriculture. A coffee company for traceability of its coffee, a frozen product company assuring consumers on the provenance of their fish products, and a big retailer for food-oriented disease outbreak. The authors note that all these BCs are private permissioned. Shahid et al. [25] proposed a model categorized into three layers: the first layer, data layer handles the interactions between entities in the SC. The second layer is the BC layer that handles the data of transactions and deliveries and also the reputation of entities involved in the system. The third layer is essentially the storage layer. This structure intends to improve throughput, lower latency and improve scalability. Tsang et al. [26] proposed a BC-IoT that uses various sensors to gather data on the food package, then stores this data on a BC. A fuzzy logic system uses the sensor data to estimate time of perishable product on shelves and how their quality deteriorates. Danese et al. [27] examine five cases of wine companies that use BC as an anti-counterfeit in SC management.

Furthermore, smart and precision agriculture have started to use the IoT extensively for their vast networks of sensors and smart devices, as well as edge computing. A known issue of IoT is its high vulnerability to hacking attacks, data leakage and privacy. BC's main qualities as a shared ledger that promotes immutability and enhanced security of information find further application in IoT networks, strengthening their resilience against security breaches and privacy violation. Chen et al. [28] proposed a framework using BC as a database for all data produced by an IoT network of sensors in a farm in order to improve on asymmetric information, unreliable third-party institutions, and poor traceability of organic food. Ferrag et al. [29] summarizes 12 works of previous papers that provide solutions to privacy preserving in agricultural IoT networks by means of BC application. A further work implements a Distributed Ledger for IoT systems utilizing IOTA and exploiting edge functionalities to the end of enhancing overall security [30]. Song et al. [31] proposes a relay-aided BC based transmission system for smart devices and sensors in rural areas as an alternative to conventional cellular network communication, in order to address security and connectivity issues. Bera et al. [32] propose the following: A security scheme, namely the BC-based authentication and key agreement in IoT-enabled agriculture environment using drones. The data is securely gathered by the GSS from the drones, while the drones also collect data securely from their respective deployed IoT smart devices in flying zones. After transactions formed with the secured collected data, the GSS sends the list of encrypted transactions along with their signatures to its associated cloud server in the BC center. The cloud server is then responsible for mining the blocks using the Practical Byzantine Fault Tolerance (PBFT) consensus algorithm to verify and add them in the BC.

Another application of BC technology in agriculture, is in the agricultural insurance sector. It provides the opportunity of automating insurances and ensuring to the farmers that if the circumstances for activating the insurance recompense are met, it will be handed automatically to them without unnecessary paperwork or delays. Sushchenko and Schwarze [33] proposed an index-based insurance BC system, where various on-field sensors measure different parameters (e.g. temperature or soil moisture, etc.), and if these parameters meet certain conditions, the insurance recompense is given to the farmer through the completion of a smart contract on a BC. Bolt [34] refers to other two attempts to improve insurance transactions in Agriculture. The first is called Etherisc, which enables recompenses automatically through smart contracts triggered by natural disasters reported by governmental agencies. The second is called SmartCrop and it aims to help farmers get a part of the insurance payment before the natural disaster has hit. This should support farmers in preparations for the coming disaster and in taking the best measures they can to mitigate loses when it eventually hits.

Furthermore, more general ideas have been proposed such as: A credit evaluation system is in pilot stage based on the Hyperledger Fabric. It involves a BC ledger where various stakeholders rate each other by awarding credits, therefore building trust in the SC [35]. Zhao et al. [36] mentioned an idea of an agricultural BC application: a BC-enabled peer-to-peer trading platform (Water Ledger) that would allow more irrigators to participate in the platform that entitles and allocates water securely and transparently, further boosting the overall efficiency of water resources.They have also built a model of manufacturing service information based on BC principle and cloud computing, which theoretically solves the problems of sharing and securing the manufacturing resources, recalling the product data and guaranteeing the quality of the processing.

In the following sections of this paper, a literature review is carried out with the aim of analysing the challenges of applying BC technology in the agricultural sector.

III. LITERATURE REVIEW

A. PESTELS FRAMEWORK

The analysis carried out is based on the PESTELS framework [37], which provides a useful approach in order to determine the different factors that need to be considered with reference to a topic. To this end the factors considered are classified into: Political, Economical, Social, Technological, Environmental, Legal, and Security.

- The Political factors associate with the needed actions at policy maker level, including adoption of regulations and standards, or regulatory changes.
- The Economical factors refer to issues related to economic performance of an industry, productivity, efficiency, and associated costs.
- The Social factors are relevant to overall culture, acceptance of change, trust, necessary skills, and relevant attitudes of the different stakeholders involved.
- The Technological factors deal with the technology aspects and relevant specifications in order to match the stakeholder requirements.
- The Environmental factors regard the environmental impact and address sustainability issues.
- The Legal factors address legal aspects associated with a domain as well open issues that need to be resolved at legislation level.
- The Security factors refer specifically to cyber security aspects that affect a domain.

The PESTELS framework has been used to determine and classify the different types of challenges arising for the adoption of the BC technology in agriculture. The framework was also used during the screening phase of the review in order to determine which papers should be excluded and which papers should be kept. The screening process is described in more detail in the following Review Methodology section.

B. REVIEW METHODOLOGY

The scope of this review was to answer the two research questions posed. To target as wide a scope of works as possible concerning the application of BC in agriculture, the databases of Scopus and Web of Science were searched for the following query:

- "Blockchain" OR "Distributed Ledger"
  AND
- "Agriculture" OR "Farming" OR "Agrifood" OR "Agrichain"

After a quick observation of the results pointing out Food Supply-Chain (FSC) as a main application domain, it was decided that a more particular focus should be given to BC application in FSC. Therefore, two additional searches were conducted in Google Scholar with the following queries:

- allintitle: "Blockchain Food Supply-Chain"
- allintitle: "Distributed Ledger Food Supply-Chain"

Furthermore, additional prerequisites that these records should fulfil in order to pass to the screening phase were:

1) Records should be written in English.
2) They should have been published after 2016.
3) They should be journal articles.
4) Relevant journals should be categorized in Q1 or Q2 quartiles.

After eliminating the records that did not meet the prerequisites, what remained reached the screening phase. During this phase, the records were skimmed through by the reviewers for mentions of any challenges that could be relevant to the RQs and could fall under any of the seven categories of the PESTELS framework. Records with no mentions of challenges for BC adoption were not considered.

Finally, a more targeted search was performed through Google Scholar, to refine the results and ensure that no important papers, which mentioned challenges befitting the RQs, were excluded. This search was supposed to be limited and target only highly cited publications, even if they were not journal articles. These Google Scholar records were added to the records that survived the first screening. The total passed on to the second phase. During the second phase, the reviewers read each record meticulously, and highlighted phrases that fell under any of the PESTELS seven

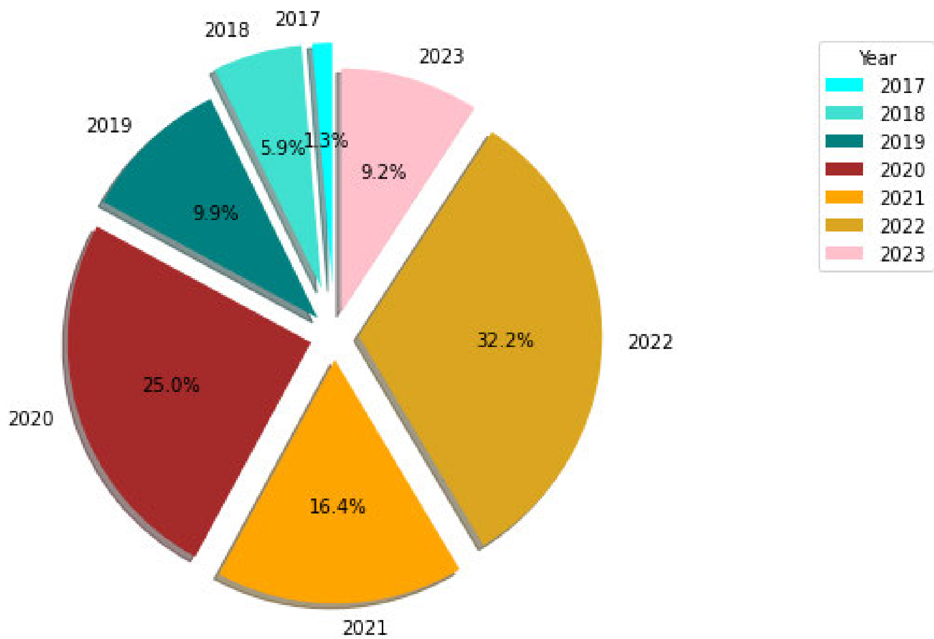

FIGURE 1. Papers included in the review.

factors. All these phrases were gathered together and grouped according to their meaning and challenge they describe. The following tables summarize all challenges associated with the implementation of BC in the agricultural sector which were retrieved from this process. All in all, the total number of records included in this review is 152. Figure 1 presents the percentages of the papers included in the review depending on the year they were published. The Literature Review table (Table 1 to Table 8) presents each record and its main contribution. The different works reviewed present specific challenges that have been classified according to the PESTELS methodology and are presented in Section IV. Identified challenges associated with technological and security aspects, also represent the research gaps appearing in the set of 152 works reviewed.

IV. CONTENT ANALYSIS

A. RESULTS

In this section, an extensive explanation of the PESTELS tables is provided. In precise, the description of each group of challenges following the PESTELS categorization is analysed. Figure 2 presents an overview of these challenges in accordance with the PESTELS framework. Figure 3 presents the number of papers included in the review which mention at least one challenge regarding BC application. The number of records referring to at least one Political, Economic, Social, Technological, Environmental, Legal or Security challenge are 57, 64, 63, 131, 18, 55 and 69 respectively.

Statistics for the distribution of challenge mentions along the PESTELS categories can be found in Figure 4. It more specifically provides for each category of challenges its minimum, first quartile (25% mark), median, third quartile (75% mark), and maximum challenge mentions. Outliers indicate existence of most noted challenges for the adoption of BC technology, per challenge category. For the Political group, (P2) - policies and regulations for the implementation of BC technology is the most mentioned. For the Economic category, (E1) - high costs for application of BC technology, and (E2) - high costs for the maintenance of the BC system, are most noted outliers. With reference to Social challenges, (S3) - lack of sophistication, skills, and technical awareness for the application of BC is the most noted. Furthermore, in the Technological group (T4) and (T5) related to storage capacity issues, (T27) on poor interoperability and lack of standardization, (T39) related to latency, and (T40) on scalability issues, are the most noted. As far as Legal and Security groups are concerned, (L1) - lack of standards about BC technology, (Se1) - cyber security threats, and finally (Se11) and (Se12) related to privacy issues, such as decentralisation contrary to anonymity and information leakage, were the most noted ones.

1) POLITICAL CHALLENGES

a: GOVERNMENTAL SUPPORT FOR SUSTAINABILITY (P1)

Governmental support on adoption of BC technology is lacking. Governments don't encourage the growth of BC-minded ecosystems in agrifood chains [50]. In particular, insufficient support is shown towards small farmers who employ sustainable practices [67]. Luo et al. [125] highlighted the importance of the continuous governmental support which is necessary for the implementation of BC technology.

b: POLICIES AND REGULATIONS (P2, P3, P4, P5)

The general lack of regulatory and legal requirements to reinforce the deployment of BC-based systems [73] is an issue.

TABLE 1. Literature review table(Part 1).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Ge et al., 2017	[38]	The authors highlight the relevance of the implementation of Blockchain (BC) in the agrifood domain. A description about the Proof of Concept application in a use case is given, as well as a presentation about the main findings of the work. Finally, the findings of the research are discussed, and the authors offer some policy recommendations about the implementation of BC in agrifood.
Lin et al., 2017	[39]	This work reviews a large body of papers and gives information on BC application in many different sectors(agriculture, healthcare, finance, technology, energy, trade, government services, e-commerce, shipping, aviation and automotive sectors). It also presents the managerial implications, societal impacts and challenges of BC implementation in Supply chain (SC) management.
Kim et al., 2018	[40]	This research gives some examples of companies that already use BC, and discusses the finance aspect of these cases. It also refers to the challenges of implementing BC. The authors sum up some of the most important key takeaways of BC implementation for traceabillity of FSCs.
Mao et al., 2018	[35]	Presents an Deep Learning technique that evaluates the transactions between stakeholders in a BC system. It also presents some of the related work done in the field of the application of BC in supply chain management and food traceability/safety systems. Finally, it gives an overall conclusion about the results that were retrieved from this Deep Learning technique.
Kamath et al., 2018	[41]	The authors discuss the importance of implementing BC technologies in FSCs, by giving some unique examples of real-life cases. Two pilot implementations of BC for food traceability done by WallMart are presented and analysed.
Galvez et al., 2018	[21]	The matter of BC implementation in food traceability and in FSCs is exhaustively discussed, by giving a multitude of examples and many possible results. In addition, the authors present the the main challenges for implementing this technology.
Reyna et al., 2018	[42]	The authors of this paper give a thorough analysis for combining BC technologies with IoT networks. In precise, they present the BC technologies and they discuss it's main implementation challenges. Later, the integration of BC and IoT is addressed, analysing also the challenges this integration involves. In addition, the authors present a variety of platforms that these types of systems can be developed.
Tan et al., 2018	[43]	The authors of this paper investigate the processes of BC implementation in Food-Supply Chain (FSC), using the case-study of Wal-Mart. In addition, there is a thorough identification of the challenges and benefits of adopting this type of technology. The case-study and the thematic analysis of it, as well as a literature review, are used as research methods to investigate this field further.
Petersen et al., 2018	[44]	The authors conducted an online survey regarding the expectations towards BC among SC industry professionals. The respondents realize the impact of BC, but the more conservative logistics companies are hesitant to dedicate resources to BC research. Then, the authors investigated 49 applications and categorised them in 3 clusters: Tracking of products during their journey through the SC, tracing back the product to its origin, and SC finance. It concludes that small scale applications are vital to understand the prospects and the barriers of BC.
Perboli et al., 2018	[45]	This paper overviews BC and the related literature. It describes a standard methodology using the GUEST system to design BC technology use cases. Finally, it presents the results of a use case in the fresh food delivery chain.
Leng et al., 2018	[46]	The authors of this paper propose an agricultural business resource BC with double-chain structure, for use in a public service platform. They also present and analyze some experimental results and tests they did on top of it throughout Matlab.
Bolt et al., 2019	[34]	This paper presents some of the potential effects and dangers in the sector of climate change for Kenya's agriculture scene and then it gives an overview of BC technology, and presents some real-world implementations of it carried out in sectors like agriculture and FSCs. In the main part of the text, the authors discuss how BC can help give solutions to Kenya's agricultural problems.
Casino et al., 2019	[47]	At first, the authors of this paper present some of the main concepts and functionalities of BC usage in FSC traceability systems. Then, they present a model for decentralized and automated FSC traceability based on BC. For assessing the feasibility of the proposed modeling approach, a use-case scenario is described. Finally, the authors give an overview of the impacts and functions of the model they presented .
Lamtzidis et al., 2019	[30]	The authors present their proposed implementation of a simple sensor data marketplace and sensor data aggregation system for precision agriculture, which relies on data integrity and auditability. They implement a distributed ledger for IoT systems utilizing IOTA and exploiting Edge functionalities to the end of enhancing overall security. Their work contributes to the relevant Open Source Community both for IoT and BC.
Pearson et al., 2019	[48]	This review paper synthesizes an overview of the implementation of BC and DLT technologies in FSC systems. In precise, at first the authors present the key functionalities of BC, while later, they give some details about why and how these type of technologies could benefit the FSC. Lastly, they highlight some of the challenges for implementing BC.
Creydt et al., 2019	[49]	The authors of this paper examine the issues of food safety and integrity. They discuss that the DLT and BC systems can play a major role in FSC in order to guarantee food safety and traceability by giving examples of use cases.
Saberi et al., 2019	[50]	The paper focuses on supply chain networks and adoption of BC technology showcasing its applicability in different usecases. Then challenges and barriers are identified and structured into 4 categories: intra-organizational, inter-organizational, system-related and external. Finally, a research agenda and 7 propositions for future research are given.
Zhao et al., 2019	[36]	This paper starts by explaining the basics of BC, then by presenting its research methodology which is Citation Network Analysis. Following this methodology it distinguishes the four fields commonly discussed in literature for application of BC in agriculture: traceability, agrifood value chain and information security, agrifood manufacturing, sustainable water management. Then the challenges to apply BC are presented, followed by a table with possible solutions to them, and advantages and disadvantages for each solution.

TABLE 2. Literature review (Part 2).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Hughes et al., 2019	[51]	In this article, BC principles are explained and then some of its benefits are outlined as well as some of its organizational applications and realities for mass adoption. It then discusses technical and societal challenges and managerial implications.
Tsang et al., 2019	[26]	This paper proposes a BC-IoT system for food traceability and time proportional quality estimation of perishable products. The system uses various sensors to gather data on the food package, then stores this data on a BC, that is both lightweight and vaporising, in order to handle big amounts of data from the IoT sensors. Also it uses a novel consensus algorithm called Proof of Supply Chain Share. Finally, a fuzzy logic system uses the sensor data to estimate time of perishable product on shelves and how their quality detoriates.
Morkunas et al., 2019	[52]	This article analyses BC from a perspective of managerial application Building on the business model framework by Osterwalder and Pigneur, it outlines the effect that BC technologies can have on each element of a business model, along with illustrations from firms developing BC.
Montecchi et al., 2019	[53]	This paper analyses how BC technology can help customers trust more the food products they consume by assuring quality provenance. It describes the various types of assurances the BC offers, namely: traceability, certifiability, trackability and verifiability.
Antonucci et al., 2019	[54]	This work addresses BC application in the agrifood sector from a computational and an applicative point of view. While most reviewed studies analysed software aspects such as smart contracts and architecture there was a fraction of works that focused on BC knots, and how they can take on the role of storing and distributing updated copies of blocks in a FSC scenario.
Casino et al., 2019	[55]	This paper follows a systematic review format to present various applications of BC across different sectors such as FSC, IoT, buisness, healthcare, data management, and privacy. It also presents BC challenges in detail, while also identifying key research gaps that will play an important role in future scientific literature as well as engineering development.
Peña et al., 2019	[56]	This article presents a systematic review on BC in FSC management in Ecuador. The results of the study suggest that application of BC for the enhancement of Ecuadorian FSC technologies have been explored by only two scientific articles and the authors suggest that there is more room for research and application of BC in Ecuador.
Drobyazko et al., 2019	[57]	The article examines the impact that the ethical, technological and patent aspects have on the distribution and societal acceptance of BC. It singles out the stages of technological adaptation from the point of view of the global community: single applications, localization, substitutions, transformation and ethics. Significant problems that impede widespread BC distribution include: problems in patenting, corporate structures and practices, state regulations, as well as the social awareness and the ethical issues regarding the technology.
Li et al., 2020	[58]	This paper presents some of the main concepts of BC technology. Then, it discusses some of the challenges of implementing BC in the agricultural sector. It also presents some experiments that were done in order to measure the sustainabillity of e-agriculture when BC is incorporated.
Roeck et al., 2020	[59]	Presents the effects and the results of implementing DLT in SCs, throughout studies and interviews that were done by the authors. It then discusses the impact of DLT in transaction cost economics (TCE) of SCs. Finally, it gives an overall conclusion and presents the results found of DLT in TCE dividing them into managerial and theoretical implications.
Chen et al., 2020	[28]	Analyses the potential usage of BC technologies in agriculture. It presents the political point of view for this topic, discussing the agricultural democratization.
Tipmontian et al., 2020	[60]	In this paper, at first BC functionalities are analyzed, as well it's potential implementation in food supply chains. Later, the authors give a brief overview about some of the existing work done in this sector. Finally, they present a case study that was done for the BC adoption and it's use for safe food supply chain management.
Iqbal et al., 2020	[61]	The authors present an IoT-based system that can prevent animal attacks in agricultural fields. They also proposed a BC-based framework for agriculture-SCM that integrates the existing IoT-based solution to enhance traceability and transparency of food products.
Ferrag et al., 2020	[29]	At first, this work provides a four-tier green IoT architecture for the agricultural sector. As it goes on, it also presents and analyzes threat models against the IoT systems used in agriculture, dividing them into different categories. In addition, the authors discuss the privacy-oriented BC-based solutions, as well as suitable consensus algorithms for green IoT-based agriculture.
Vangala et al., 2020	[62]	This paper conducts a systematic review on the use and applications of BC in smart agriculture for providing mostly security goals. There was also an analysis on the security attributes, application areas, and cost of computation and communication that are involved in the field of BC-based IoT systems for smart agriculture.
Bumblauskas et al., 2020	[63]	This article presents a use-case for the deployment of BC in food distribution, and specifically in egg SCs. In this paper there was also presented a literature review of BC concepts and applications. The authors highlight some of the most important benefits of implementing BC technologies in the egg SC that they studied, as well as some of the overall black-points that BC implementation can cause to FSCs.
Hang et al., 2020	[23]	This paper presents a system based on BC combined with IoT, for usage and monitoring in fish farming. In precise, they give a thorough analysis of the functionalities of this system, as well as the whole procedure carried out to create it. Next, they evaluate the performance and the functions of the system, throughout some analytic procedures.
Akram et al., 2020	[64]	In this article, the authors present a systematic review of existing BC-based solutions, with a focus on Industry 4.0-based applications. In addition, they identify a number of research opportunities in various application domains, as well as discussing posible future implementations.

TABLE 3. Literature review (Part 3).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Xu et al., 2020	[65]	The authors of this paper give an in-depth analysis for the BC usage in order to guarantee food safety and integrity. At first, they present some of the main concerns about food safety issues, followed by a brief overview of the BC technology functionalities. In addition, the authors present a literature review about the BC implementations in FSC systems. Finally, they present some of the main challenges for adopting this technology.
Mirabelli et al., 2020	[66]	The authors of this paper present a review of a literature about the applications of BC in the agricultural sector, with a focus on food traceability issues. They also present some of the existing work done, regarding the development of BC-based traceability systems in agriculture. Finally, they discuss open research questions.
Frank et al., 2020	[67]	This work addresses small farmer problems, and how smart contracts can ease them. It describes how smart contracts can address the challenges that small farmers face by guaranteeing insurance recompensations and by making management of the SC easier for the farmer. The paper concludes that smart contracts must become more user-friendly for small farmers and their needs so that these small farms can survive in a world of growing agricultural demand
Yadav et al., 2020	[68]	The authors of this work identify ten barriers common in BC literature, and proceed to ask BC experts on their opinion on how these barriers relate between them. After enough questions, they apply the Delphi consensus building technique to determine a hierarchy for these barriers, distinguishing more important ones from less. The study goes to show that the two biggest barriers are lack of government regulation, and lack of trust among agro-shareholders, while the two less important ones are high energy consumption, and updated infrastructure for SC companies.
Patelli et al., 2020	[69]	This review paper starts by summarizing what BC is, then proceeds to describe its various use cases and applications in agri-food SC traceability. It describes the BC's challenges and limitations as well as presenting a scheme to determine if a company should invest in the technology or not based on their particular needs (need for private or public data, all stakeholders trustable or not, etc.)
Xiong et al., 2020	[70]	The authors , at first, describe the disruptive potential of BC technology. Then, the potential advantages in four different sectors: Agricultural Insurance, Smart Agriculture, Food Supply Chain, E-Commerce of Agricultural Products.It closes by providing the technology's general limitations. The paper has a particular focus on the differences between small holders and large farms.
Dutta et al., 2020	[71]	This paper starts by describing the democratisation of data the BC brings, as well as the advanced security. It then describes a theoretical model of how to apply an Information Communication Technology (ICT) e-agriculture system model with BC infrastructure at a local and regional scale. Then it presents an evaluation diagram for managers, to help them decide if it's worth investing in BC, and it concludes with the technology's challenges and limitations.
Singh et al., 2020	[72]	This paper reviews all works on the two sectors of BC and IoT that contain the words Blockchain , IoT and/or AI. It briefly expands on the general points made by these papers for the two sectors and then concludes with a short statistical analysis of how the terms Blockchain, IoT and AI are distributed in the sample of around 32 papers.
Lin et al., 2020	[73]	In this review various concepts of BC technology are explained, including its data storage ecosystem and its several popular application platforms. A detailed investigation of disparate BC applications in the agricultural sector. is carried out . Finally, a discussion of how the current applications of BC would perform under stress for a reason such as COVID-19 is discussed and some ways to ameliorate their performance are given.
Shahid et al., 2020	[25]	This work proposes an end-to-end BC solution for agri-food SC. The proposed model is categorized into three layers: the first layer, the data layer handles the interactions between entities in the SC. The second layer is the BC layer that handles the data of transactions and deliveries and also of the reputation of entities involved in the system. The third layer is essentially the storage layer. Finally, the paper describes security vulnerabilities of smart contracts, and concludes with future improvements.
Fu et al., 2020	[74]	This article examines the management mechanism coupling between BC and agri-food SC from the perspective of institutional economics. It analyses the institutional arrangement of the BC technology describing net chain structure, transparency and smart contracts. Then, it analyses the institutional skeleton of the Chinese agri-food SC and discusses how BC can amend many of its problems.
Catalini et al., 2020	[75]	This paper deals with how BC can reduce the cost of validation and the cost of networking in a digital transaction system. The cost of validation refers to the cost of validating any information that describes a transaction, and it's a high cost in centralised systems. Contrary BC can bring this cost close to zero under certain circumstances but not always. The cost of networking refers to the cost of spreading and maintaining a network of digital transactions. In this case permissionless BCs reward networking, reducing its cost in contrast with permissioned BC which still rely on certain participants to maintain the network.
Behnke et al., 2020	[76]	This paper addresses the various prerequisites (boundary conditions) for traceability and how these can be covered by BC. Interviews on actors on four different dairy product chains are conducted and some boundary conditions for traceability are extracted. Then, a discussion ensues about which of these conditions the BC can fulfill and which version of the BC is right for the job ("public permissioned")
Gunasekera et al., 2020	[77]	This paper ponders on the economic effect the adoption of BC could have on the Australian Grains trade. First, it provides an analytical framework on which the analysis will be based. Then it provides the scenario analysis of the potential economic effects and its results, including a simulation of the effect the adoption would have on the market.
Chang et al., 2020	[78]	This work discusses the application of BC in global SCs. First, it discusses how BC can tackle critical points in current SC management and global trade. It goes on to present a taxonomy of the pilot initiatives on this front. Then, it presents the challenges of widely implementing BC in the private sector. It then discusses the ongoing pilot efforts, implications, and challenges of BC for customs and other governmental agencies and it concludes by proposing collaborative interventions and future research directions.

TABLE 4. Literature review (Part 4).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Liu et al., 2020	[79]	This work analyses the application of BC in agrifood supply chain from the point of how mitigating the ability of a producer to lie about the freshness of their product, impacts the product's final price. Supposing that the BC prevents producers from lying about the freshness of their products, the paper argues through math formulas and various hypotheses, that the price of a product becomes lower and the revenues become higher for all involved in the SC.
Motta et al., 2020	[80]	The authors of this article aim to investigate the application of BC in the agrifood industry, by following a review of already existing research works and case studies focused on the early adopter companies. Finally, they present their findings and their conclusion, as well as limitations and recommendations of their work.
Lezoche et al., 2020	[81]	This review presents four main technologies to be applied in agriculture. IoT, BC, Big Data, and AI. Two main conceptual pillars, impact and challenges, arising from the use of various technologies are presented. Impact can be functional, economic, environmental, social, business-related and technological.
Upadhyay et al., 2020	[82]	The authors of this paper present a systematic review of the scholarly research work published on BC, with respect to perceived challenges, opportunities, and application focus. In addition, they specify significant insights for practitioners to assess their requirements and resources to adopt and deploy BC .
Torky et al., 2020	[83]	This paper reviews BC applications in IoT networks. Firstly, the study reviewed solutions by which BC can solve security and performance challenges of IoT-based network systems. Secondly,it proposed some BC models that can be implemented in five uses cases in precision agriculture. Thirdly, the study reviewed and discussed some BC platforms used to digitally manage various subsectors in precision agriculture, such as crops overseeing, livestock grazing, and food SC.
Kamble et al., 2020	[84]	This paper reviews current BC bibliography, identifying 13 benefits (called enablers) of adopting the BC in FSC. Then, it asks experts on the field to evaluate these enablers and applies to them the ISM-DEMATEL methodology in order to construct relationships between them and determine their importance. Traceability is deemed to be the most important. Finally, the paper discusses repercussions of the work and future research directions.
Duan et al., 2020	[85]	This paper applies a content-analysis based literature review in BC adoption within FSC. It introduces four benefits. BC can help improve food traceability, information transparency, and recall efficiency. Moreover, it can be combined with Internet of things (IoT) to achieve better security and efficiency. In its second part the paper identifies five main challenges of applying BC to agriculture: lack of deeper understanding of BC, technology difficulties, raw data manipulation, difficulties of coordinating stakeholders, and deficient regulations.
Kamble et al., 2020	[86]	This review takes articles that use new data-driven technologies such as IoT and BC in SC, and tries to identify in four main points why these technologies need to be used and how they are used. These points include: The level of analytics used (descriptive, predictive and prescriptive), sustainable agriculture SC objectives attained (social, environmental and economic), the SC processes from where the data is collected, and the SC resources deployed for the same. Based on their analysis, the authors identify the two main points of applying the technologies: SC visibility and SC resources.
Tiwari et al., 2020	[87]	This paper presents how BC is applied in agricultural SC, by providing a description of the stages of an SC and then discussing how the BC applies to each stage. It then analyses two case-studies, identifying several benefits, such as transparency of product provenance and protection of human and worker rights.
Mistry et al., 2020	[88]	This paper presents a survey for scientific works that use 5G-enabled IoT for BC industrial automation, for various applications such as Smart Agriculture and Smart Cities. The survey presents the state-of-the-art works on the BC-based industrial automation using 5G-IoT, by listing their merits and shortcomings, allowing readers to pick the one which suits them best
Demestichas et al., 2020	[89]	The authors of this paper conduct a thorough research in the literature concerning traceabillity techniques and BC technologies and their combination in the agricultural sector. They also discuss some of the main challenges for implementing BC in the agriculture, while they also give some topics for further investigation in the future.
Wamba et al., 2020	[90]	The authors of this paper present a literature review and give a in-depth discussion about the role of BC in creating value in the domain of operations and SC management.
Rejeb et al., 2020	[91]	This paper does a review of current literature on BC technology in FSC. It uses a body of 61 papers. A clustering of papers based on words found in the title, abstract and keywords is conducted to find the most relative and frequently mentioned words and how they correlate between them. Then an analysis of benefits, challenges and future research venues, based on these 61 papers, ensues and the paper concludes.
Sushchenko et al., 2021	[33]	Presents the the possible benefits of implementing BC and DLT technologies for an improved Index-Based insurance in Agriculture. At the beginning, it discusses the climate change as a window of opportunity for the insurance sector. It goes on to give a systematic approach for the climate insurance in agriculture, as well as the application of DLT in it.
Chen et al., 2021	[92]	Presents the design of a BC-based framework for use in agrifood SC. Then, it proposes, describes and discusses, the use of a Deep Reinforcement Learning algorithm in SC, in order to make decisions in the production and storage of agrifood products. It finally compares this method with similar ones found in the literature.
Durrant et al., 2021	[93]	This paper discusses the usage of a variety of different technologies, including BC, for addressing problems of data sharing in the agrifood sector. In precise, the authors at first give a description of data-sharing issues, functionalities, needs etc. Then, they describe and analyze the use of different technologies for sustainable data-sharing and how the technologies can address those issues.
Sengupta et al., 2021	[22]	This paper at fist presents some of the main functionalities and benefits of BC technologies. Later, it gives an in-depth analysis on the potential challenges that this technology can take care of after it's implementation in the agrifood sector. The authors also discuss some of the requirements for implementing BC. Finally, they give an overall conclusion by presenting some recommendations for the BC adoption in agrifood SC systems.

TABLE 5. Literature review (Part 5).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Katsikouli et al., 2021	[94]	In this paper, the authors discuss issues of food safety, food authenticity, fair trade of food, environmental impact of food, and animal welfare, as well as the potential application of BC technologies in order to tackle them. Next, various use cases with potential implementation of BC are illustrated.
Verma et al., 2021	[95]	The authors of this paper at first mention concepts and fundamentals about the agrifood frameworks, and how they can impact today's world. Next, they present and discuss an agromanagement system based on BC.
Cao et al., 2021	[96]	The authors of this paper created and tested a BC-based traceability system throughout a cross-border beef supply chain between Australia and China. In addition, relevant literature was reviewed to underpin the development of a BC solution for a trusted SC. The BC prototype was developed taking into account opinions from both Australian producers and Chinese consumers.
Griffin et al., 2021	[97]	The authors of this paper give a thorough analysis of the possible DLT implementation in the agricultural SCs. Firstly, they analyze this type of technology and they present the benefits by adopting it in farming, focusing more in the data integrity. In addition, they discuss the implementation of DLT in a use case of cotton SC.
Kramer et al., 2021	[24]	The authors of this article give an extensive presentation of a literature research about the differences between traditional and BC-based FSC networks in the agrifood sector. Based on this literature overview, they also identified the key coordination mechanisms that are supported differently depending on the selected BC platform types. Next, they discuss their findings with use cases from the agrifood industry.
Saurabh et al., 2021	[98]	This study conducted a survey about BC adoption on agrifood stakeholders. By their answers, the authors identified six factors and their discrete levels as the potential drivers of BC technology adoption which were preferred by the survey respondents and exhibited optimal utility value for the supply chain. Then, it described the architecture of various BC modules, utilising smart contracts, machine learning and IoT, for addressing each of the factors discovered by the survey.
Rana et al., 2021	[99]	This paper carries out a systematic literature review on BC applied to sustainable agrifood SC. It starts by explaining in detail the review methodology that produced a body of 80 papers. It presents the results of reading those papers, namely the advantages of applying BC to agrifood SC, and the various applications that have been attempted so far.
Casino et al., 2021	[100]	This paper suggests a BC-based framework for FCS traceability. BC is used as a distributed tamper-proof mechanism and smart contacts as an automation mechanism for managing SC stakeholders and processes as well as for product definition and creation. A case scenario is presented of a local food provider(dairy company). The information on the smart contracts can range from temperature and results of chemical tests to ID of product. Moreover, it can provide information on stakeholders (distributors, retailers) and how many products they have at their possession in the given moment.
Jabbar et al., 2021	[101]	This is work addresses the existing drawbacks of supply chain systems and how these are dealt with by BC. It then summarizes a range of state-of-the-art consensus algorithms and thoroughly analyses the major challenges in the adoption of BC for supply chain. Finally, it identifies challenges associated with future research and proposes a model called MOHBSchain for the adoption of future BC-enabled supply chains.
Danese et al., 2021	[27]	This paper analyses five use cases of BC technology in the wine supply chain sector. In the beginning it presents some theoretical background on the design of anti-counterfeit measures, and an overview of the relevant BC literature. Then it goes on to present its research methodology: It examines five cases of wine companies that use the BC, and analyse how they use it and why. It then extracts conclusions regarding the use of BC as an anti-counterfeit in SCM.
Song et al., 2021	[102]	This paper proposes a relay-aided BC based transmission system for smart devices and sensors in rural areas as an alternative to conventional cellular network communication
Song et al., 2021	[31]	This work discusses a consortium system based on BC for Agri-food SC. The main idea will be a decentralised platform on which every producer has access, and has a rating depending on his/hers production quantities and qualities and other factors. Buyers can find producers on this platform and an algorithm decides, based on the previous rating which producer is best suited to the particular buyer. The various values of each producer are sampled from special sensors and stored on the BC.
Debauche et al., 2021	[103]	In this article, the authors give a thorough and an in-depth analysis of the architectures and the procedures that are used in Smart Farming. Furthermore, the authors refer to BC and DLT for possible implementation in Agriculture 4.0 combined with IoT, in order to achieve a more sustainable and well-functional Smart Farming architecture. Finally, they present their findings and they give their conclusion.
Kassanuk et al., 2021	[104]	The authors of this article give an in-depth description about the BC-based agriculture infrastructure that records data about farmers. In precise, they are focusing mainly in the discussion of BC functional features, and how these can be used in a safe and secure manner for agriculture.
Nurgazina et al., 2021	[105]	The authors of this article present a thorough literature review whitch provides a contribution towards outlining the current applications of BC, DLT and IoT in the FSC domain, describing initiatives, discussing the challenges of implementing BC, as well as referring to future research directions.
Barbosa et al., 2021	[106]	This paper conducts a bibliometric review of new technologies in the agricultural sector. A set of 1236 papers was analyzed in terms of citations, frequently used keywords, new research themes and hot research topics. All this were clustered then visually depicted.
Stranieri et al., 2021	[20]	The authors of this paper present an integrated framework for usage in FSCs which uses BC technology, including a broad set of performance dimensions referred in literature. The outcomes of this study prove that this technology positively impacts SCs.

TABLE 6. Literature review (Part 6).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Ronaghi et al., 2021	[107]	The present study provides a model for evaluating the maturity of BC in the agricultural SC. The dimensions of BC are ranked by agricultural experts using the SWARA method. Then, the authors design a model to evaluate BC maturity according to each dimension. Finally, the ensuing model is tested by questioning the staff of a company active in agricultural SC. The research findings show that smart contracts, Internet of Things (IoT), and transaction records are of the highest importance among the BC dimensions.
Rocha et al., 2021	[108]	This paper conducts a PRISMA-based systematic review to identify the purpose of using BC in the agribusiness sector. The study concludes that current research is only at an early stage, since most prototypes are only developed within controllable laboratory confines, and have not been tested in real world scenarios. Furthermore, the study suggests that in the near future, BC will be increasingly applied across all economic sectors, including agribusiness.
Dey et al., 2021	[109]	This study performs a literature review on BC technology in agriculture. It theorises that BC application in agriculture is comprised from five stages which include data collection, data security, data storage and data transmission. The types of data according to this study are four: Enironmental data,production data, administrative data and external agency/supply chain data. Based on the preceding analysis the paper presents a BC-IoT theoretical architecture aiming to standardise BC and IoT use for sustainable e-agriculture.
Li et al., 2021	[110]	The authors of this paper introduced the major BC platforms currently used in FSC. Next, they conducted a synthesis analysis to explore the benefits and challenges of BC technology in FSCs.
Bera et al., 2022	[32]	This paper proposes a security scheme, namely the BC-based authentication and key agreement in an IoT enabled agriculture environment using drones. The data are securely gathered by the GSS from the drones, whereas the drones also collect data securely from their respective deployed IoT smart devices in flying zones. After transactions formed with the secured collected data, the GSS sends the list of encrypted transactions along with their signatures to its associated cloud server in the BC center (BC). The cloud server is then responsible for mining the blocks using the PBFT consensus algorithm to verify and add them in the BC. The paper also has some comparative studies between the proposed scheme and other popular schemes in IoT systems.
Paul et al., 2022	[111]	The authors present a literature review on BC and RFID for SC management and circular SC management then they address the development of a BC-driven RFID-enabled circular SC management system, for usage in the tea SC.
Pakseresht et al., 2022	[112]	This work performs a literature review on 44 scientific papers focused on agriculture, to identify the role of BC in circular economy. The findings suggest that BC has the capacity to eliminate information asymmetry and help in monitoring recycled biomass, but BC applications in circular economy have not been explored enough in scientific literature yet.
Nagariya et al., 2022	[113]	This article presents a survey in agriculture application of BC. It starts by determining current barriers to adoption. It proposes seven hypotheses as probable barriers, then asks several experts in the agri-industry to provide their view. The results of the questionnaires are analysed using structural equation modelling. The results show that all assumed barriers are real obstacles, therefore the hypothesis is validated
Anand et al., 2022	[114]	This work proposes a new method for cluster head management to improve agricultural accuracy. It does so without utilising BC, arguing that it is still an immature technology with poor scalability potential.
Vangipuram et al., 2022	[115]	The current paper uses an IoT sensor network to forecast availability of groundwater for agricultural purposes. Then, they store the sensor readings, perform double-hashing and implement control through smart contracts in a framework that combines BC and Distributed Data Storage, to achieve decentralisation and transparency
Rehman et al., 2022	[116]	This work takes the decentralised agricultural WSN architecture that utilises Cluster Heads and integrates it with a BC in order to achieve better security and energy efficiency while combining the decentralised nature of both technologies
Ahmed et al., 2022	[117]	This work overviews how new technologies such as ML, AI, BC, IoT, are used in agriculture. The main concern of the paper is how IoT, ML, and BC can be combined to serve Climate-Smart Agriculture applications.
Sabrina et al., 2022	[118]	This paper proposes a BC-based IoT network for various purposes (among them is also agriculture). BC is used to support a decentralised storage space for IoT sensor data, providing immutability and data sharing among multiple network participants.
Debauche et al., 2022	[103]	This study reviews architectures of IoT networks, some of them utilising BC, for application and transition to Agriculture 4.0 . It discusses if these architectures can be used generically for different use cases and when those architecures can become industrialised for mainstream agricultural use. It compares them according to eight criteria that include user proximity, latency, network stability, high throughput, reliability, scalability, cost effeciveness and maintainability.
Bodkhe et al., 2022	[119]	This study researches precision irrigation systems and their combination with BC. It reviews previous literature and determines, attacks and countermeasures on precision irrigation systems, how to integrate BC in order to prevent attacks, and current challenges of deploying BC in precision irrigation
Vijay et al., 2022	[120]	This study presents the methodology and some experimental results of a food tracking system called Agrichain, which is based on the BC technology. This system was implemented for grains, but the authors propose it's potential usage for any agricultural product.
L.B, et al., 2022	[121]	This study performs a thorough, in-depth review on various applications of BC in agriculture, and examines the challenges and research gaps going forward.

TABLE 7. Literature review (Part 7).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Chaganti et al., 2022	[122]	This work implements a BC-based security-monitoring framework for smart farms. BC is used in tandem with smart contracts to store security information and prevent attacks targeting other farms.
Peng et al., 2022	[123]	This research develops a model based on multi-BC for supervision of the rice supply chain. It provides a safe framework for corporate users to share and transmit useful data with different privacy levels.
Bagga et al., 2022	[124]	This work describes how BC can be used in access control protocols of an IoT network. Three different protocols are described, certificate-less, certificate-based, and BC-based and are then compared in terms of computation and communication cost.
Luo et al., 2022	[125]	This work bases its survey around the application of IoT systems for carbon expenditure mitigation. It investigates how BC can be used for this particular purpose in combination with IoT
Tende et al., 2022	[126]	The authors built a BC-based voucher system for farmers in Tanzania. Vouchers are government-issued orders in paper-physical form that allow farmers to buy fertilisers and seeds at half price, but they are prone to forgery and authority misuse, therefore the developed BC network brings trust and prevents nefarious mishandling of the vouchers.
Wünsche et al., 2022	[127]	Presents a thematic analysis about the implementation of BC technology in food systems.
Wang et al., 2022	[128]	The research goal of this paper is to clarify the influence of BC technology on the qualification rate and circulation efficiency for agricultural product
Yadav et al., 2022	[129]	This paper performs a systematic literature review on the applications of six technologies (including BC) in the agricultural FSCs, under the scope of five research dimensions: traceability and food safety, information system management, food waste, control and monitoring, decision making and agribusiness. It suggests that they will constitute low cost solutions to provide sustainability and security to agricultural FSCs.
Marchese et al., 2022	[130]	This paper presents an agricultural FSC management system based on the Hyperledger Fabric. Its effectiveness is showcased in various use cases
Seranmadevi et al., 2022	[131]	This study conducted interviews to 360 farmers in India to ascertain their knowledge of BC application in agriculture, and their opinion of it. Their answers are evaluated numerically through the Kaiser-Meyer-Olkin and Bartlett's Test, with each farmer having his/her own weight according to age, gender, land capacity, possession, education level,learned procedures, and experience. While some patterns could be assumed from correlating the weight factors to the answers, all farmers irrespectively of their factors expressed interest for a new technology that will revolutionise their sector.
Borrero et al., 2022	[132]	This paper conducts a case study for an accessible and scalable multidimensional multilayered digital platform that is focused on adding value to smallholders. This is done for determining platform governance and a data development model for a Spanish community's fruit and vegetable sector.
Wadhwa et al., 2022	[133]	This paper proposes a consensus algorithm for BC-based IoT arrangement. The algorithm is a variation on PoW, where a single miner assumes the mining task. The processing burden of mining is passed off to the edge computing side of the network, to relieve IoT nodes and enhance network efficiency.
Misra et al., 2022	[134]	In this review, the authors present an overview of IoT, big data, and artificial intelligence (AI), and their disruptive role in shaping the future of agri-food systems.
Ayed et al., 2022	[135]	The application of DNA traceability, by storing DNA data on a BC database, is presented in this work as an innovative approach to authenticate olive products is reported in this paper.
Khan et al., 2022	[136]	The experiences shared in this study can serve as lessons for practitioners to adopt the BC technology for performing agricultural supply chain during pandemic situations such as COVID-19.
Alobid et al., 2022	[17]	This work provides an overview of 79 scientific papers on the application of BC in agriculture, by describing its benefits and current use-cases.
Abijaude et al., 2022	[137]	This article presents a BC-based IoT system for added protection and security to data generated by monitoring of cocoa fields.
Dey et al., 2022	[138]	The authors of this paper present a multi-layer framework based on BC, which also utilizes cloud computing, reinforcement learning and QR codes, in order to reduce food waste.
Lee et al., 2022	[139]	This paper discusses the usage of a BC platform and presents a hypothetical use case of this technology in the dairy industry.
Bera et al., 2022	[32]	This paper presents an authentication and key management scheme for IoT-enabled Precision Agriculture utilising drones as mobile sinks, by using private BC, to reduce communication costs and augment security.
Alkhateeb et al., 2022	[140]	The authors of this paper present a systematic literature review for the application of BC platforms.
Shah et al., 2022	[141]	This paper surveys current literature on using BC technology to mitigate Distributed Denial of Service attacks on IoT networks. It suggests that all solutions can be classified in four categories Distributed Architecture-based solutions, Access Management-based solutions, Traffic Control-based solutions and the Ethereum Platform based solutions.
Khan et al., 2022	[142]	This paper discusses a collaborative approach for the application of a metaheuristic BC-based system in agriculture.
Song et al., 2022	[143]	This work proposes an evolutionary game model comprised from three types of players, governments, telecom operators, and agricultural enterprises, to analyse the dynamic between them when they choose to participate in the sustainability chain by adopting BC for FSC. The paper provides a cost-return analysis for each participant.
Yu et al., 2022	[144]	This paper presents the findings of a systematic review for enhancing security by employing BC-based solutions in IoT smart agriculture. Their findings suggest that BC constitutes a robust solution to IoT security problems

TABLE 8. Literature review (Part 8).

Literature Review Table		
Author & Year	**Ref No**	**Main Contribution**
Yang et al., 2022	[145]	This paper presents a review about the security of technologies with emphasis on authentication techniques and BC-powered schemes.
Hassoun et al., 2022	[146]	This paper analyses the transition to the new alternatives of plant based diets, their trends of these diets, as well as the safety and the nutritional value of plant-based foods. Furthermore, the authors of this paper discuss how the digitalization in the SC can support the transition to vegetarian diets and the vegetal sectors in general.
Agrawal et al., 2022	[147]	This work reviews ten different applications of BC in ten different sectors such as agriculture, banking, aircraft, and SC. It presented a taxonomy of the applications, determining the challenges and key lessons for the implementation technology in each of these different sectors.
El Mane et al., 2022	[148]	This paper presents a BC-IoT architecture for agricultural SC management, that aims to holistically address the most common challenges of BC and IoT such as storage and scalability, security, data privacy and interoperability. Possible defense mechanisms based on BC technology are also discussed.
Sahayaraj et al., 2022	[149]	This work provides a translucent fund transfer mechanism built on Ethereum. The farmers host their products on a digital platform, inviting investors. Both the farmer and investor are bounded with a transparent and tamper-resistant rating mechanism to increase credibility.
Wang et al., 2022	[150]	This paper analyzes the operation model and revenue distribution of agricultural value chains using BC.
Adow et al., 2022	[151]	This paper presents a BC based system and an intelligent model protocol for IoT devices that monitor crops.
Nguyen, et al., 2022	[152]	This paper presents a BC-based framework for developing a traceability solution as an effective method of communication between actors in the agricultural value chain toward a sustainable agricultural model
Khalil et al., 2022	[153]	The authors of this paper present an overview of security issues for IoT-based devices, and also provide an updated review of authentication mechanisms developed with BC technology.
Wang et al., 2022	[154]	This paper denies the connotation and characteristics of the green development of the whole agricultural industry chain and deeply analyzes the development status, major challenges, and feasible paths of the whole agricultural industry chain in China.
Vyas et al., 2022	[155]	This article summarizes research on the newest BC solutions paired with AI technologies for strengthening and inventing new technological standards for the healthcare ecosystems and food industry.
Rathod et al., 2023	[156]	The authors describe the application of a BC system integrated with IoT and 6G networks, to handle data integrity attacks on the crime data. Furthermore, this proposed framework is assessed considering different performance parameters, and the authors conclude by giving some future research challenges.
Zheng et al., 2023	[157]	The authors of this work present an analysis of the optimal BC-based traceability strategies of the members of the agricultural product SC under different scenarios, by using a theoretical mathematical model based on Game Theory.
Jadav et al., 2023	[158]	IPFS-based BC helps against conventional BC scalability problems and data storage capacity issues
Valencia-Payan et al., 2023	[159]	This work proposes a solution system utilising smart contracts for mishandling of products during Social Selling. The recent increase of social selling has instigated the need for better managed Social Selling SCs, and this paper proposes BC-based SC management with integrated smart contracts that validate the characteristics of products. Finally, it presents a use case that utilises IoT sensors.
Raza et al., 2023	[160]	This paper introduces the smart agriculture framework based on IoT, BC, and smart contracts . Its novelty is that it includes smart contracts that automate the intra-organizational and inter-organizational processes of the agricultural SC.
Mishra et al., 2023	[161]	This work proposes a BC-regulated automatic key refreshment mechanism for IoT systems to adress the simplicity and lack of transparency inherent in current key update process. The mechanism they present aims to decentralise the key refreshment process , which normally happens in a central server, by taking it in a BC-based network that uses smart contracts to regulate it.
Saranya et al., 2023	[162]	The current work describes a consortium BC-based traceability system for agricultural products. It utilises a novel consensus algorithm called "Proof of Transaction", which is voting-based similar to a PoS algorithm, that creates consensus groups of nodes based on the number of transactions happening in one node. According to the authors, this algorithm manages to reduce latency and improve the efficiency of the traceability system.
Vangala et al., 2023	[163]	This work proposes a key authentication scheme for an IoT network of mobile robots, that combines BC technology with elliptic curve cryptography. BC is used to avoid the privileged-insider attack which is common in key authentication schemes. BC is also useful for storing crucial sensor data in a decentralised ledger in order to avoid its corruption by malicious parties.
Zeng et al., 2023	[164]	This work proposes an IoT comprised of sensors that measure water level and seed expenditure. The proposed system utilised BC to record transactions between nodes of the IoT network in the shared ledger, ensuring transparent management of resources among farmers.
Miller et al., 2023	[165]	This paper reports on a university-industry collaborative study to leverage the use of BC-based decentralised finance technology in two ways to benefit SMEs and to address the prevalent asymmetric information risks in a SC finance context
Sharma et al., 2023	[166]	The authors of this paper discuss a sustainable Ethereum merge-based Big Data gathering and dissemination in IIoT at improving the performance of IIoT-dependent smart farming industries.
Patel et al., 2023	[167]	In this paper, the authors propose a BCbased mechanism which would address issues mentioned in the agriculture sector, by connecting various stakeholders through the usage of IoT devices and smart contracts in Ethereum.
Chatterjee et al., 2023	[168]	The authors of this work propose a framework which uses the concept of BC smart contracts as a traceability solution for food costumers, as well as, presenting the evaluation of the system.
Dal Mas F et al., 2023	[169]	The authors of this document employ an analysis in order to delineate an up-to-date picture of the current state as well as to provide integrated point of views regarding the opportunities and potentialities of BC technologies for agrifood.

TABLE 9. Challenges for implementing BC technology in the agricultural sector (Part 1).

PESTELS Analysis Table		
Political Challenges	**Tag**	**References**
Governmental support for sustainability:		
Lack of adequate governmental support to farmers for sustainability	P1	[67], [50], [113], [125], [127]
Policies and regulations:		
Lack of governmental regulations and regulation uncertainty	P2	[68], [36], [39], [73], [44], [76], [52], [81], [38], [50], [59], [34], [60], [42], [64], [104], [21], [94], [106], [89], [110] [105], [85] [55], [87], [50], [107], [129], [136], [150], [147], [167], [169]
Lack of BC-relevant data policies	P3	[21]
Lack of policies to protect user rights and trading secrets	P4	[85]
Lack of strict BC policies in the FSCs	P5	[85], [109]
Miscellaneous:		
BC's decentralized paradigm is in contrast with generally centralized government models	P6	[101], [82], [84]
Providing incentives for involvement of decision makers for BC adoption	P7	[109]
The involvement of regulatory and legal systems of different countries mandates political intervention	P8	[78], [113]
No agreed assessment of BC among government agencies in different countries	P9	[57], [113]
Economic Challenges	**Tag**	**References**
BC related costs:		
High implementation cost	E1	[40], [60], [62], [96], [97], [38], [50], [36], [39], [75], [105], [110], [109], [21], [112], [113], [114], [103], [127], [165], [169]
High cost for the upkeep and maintenance of the system	E2	[58], [30], [38], [99], [36], [111], [75], [82], [91], [54], [112], [121], [128], [130], [17], [145], [162], [166]
Replacement of existing technologies requires money and effort	E3	[38], [23], [81], [107], [157], [112], [146]
BC economic outcomes:		
Unclear economic benefits and existence of economic risks	E4	[39], [77], [74], [44], [78], [105], [91], [143], [150]
Increased price of final products	E5	[69], [89], [20]
Need for investments, incentives and new economic models:		
Lack of willingness for BC investments / Lack of investments for research and innovation in the BC sector	E6	[77], [79], [105]
Lack of contract incentive strategies among BC stakeholders	E7	[79]
Not affordable by BC stakeholders (especially small-farmers or the developing world)	E8	[48], [69], [80], [103]
Definition of economic models to apply in order to self feed SC and relative BC infrastructure	E9	[54]
Social Challenges	**Tag**	**References**
Hesitance due to technological immaturity and other barriers:		
Hesitance because of the BC's infant stage	S1	[35], [94], [50], [39], [101], [89], [90], [82], [88], [57]
Lack of infrastructures due to societal inequalities	S2	[70], [81], [77], [89], [105], [87], [157], [127], [113], [168]
Lack of knowledge, technical awareness, and skills:		
Lack of sophistication, skills, knowledge and technical awareness of BC technology	S3	[36], [34], [62], [96], [43], [63], [65], [48], [24], [38], [50], [39], [78], [81], [111], [58], [20], [60], [22], [94], [44], [78], [82], [105], [84], [89], [110], [91], [55], [109], [40], [157], [113], [114], [117], [132], [152], [167]
Farmer's and producer's ambiguity and unawareness	S4	[67], [68], [99], [110], [82], [105], [85], [113], [131]
Lack of business and management sophistication in order to implement BC technologies	S5	[48], [40], [109], [112], [116]
Limited education and training platforms	S6	[87]
Capacity of building food chain cooperatives	S7	[109]
Human errors	S8	[105], [119]
Collaboration and trust:		
Lack of collaboration and trust between BC stakeholders	S9	[43], [70], [25], [74], [81], [105], [110], [85], [56], [88], [109], [110], [39], [44], [24], [96], [82], [38], [105], [26], [157]
Lack of trust between consumers and producers	S10	[65], [39], [25], [81], [102], [105], [110], [113]

TABLE 10. Challenges for implementing BC technology in the agricultural sector (Part 2).

Social Challenges (continued)	Tag	References
Perception and acceptance of BC:		
Actual effectiveness of BC for use in agriculture	S11	[38], [110], [82], [135]
Association with cryptocurrencies	S12	[87], [50], [112]
Lack of BC acceptance in the agri-industry	S13	[44], [110], [107], [105], [38], [22], [39], [25]
Societal and market issues:		
Ambiguity in society and consumers' behaviour	S14	[50], [69], [101], [51], [81], [66], [111], [105], [89], [87]
Loss of jobs	S15	[39], [91]
Consumer fatigue due to large amount of information	S16	[53], [121]
Sectoral and company barriers:		
Agricultural sector operates under pressure	S17	[89]
Conflicting objectives for different stakeholders	S18	[39], [121]
Elimination of inter-mediators in FSC can create rifts	S19	[39]
Perception that already existing technological infrastructures within a company are enough	S20	[39], [168]
Ethics and data issues:		
Ethics, Corruption of data, Information Asymmetry	S21	[40], [96], [21], [97], [63], [23], [64], [66], [49], [25], [99], [159],
Unclear usage of information	S22	[42]
Hesitation from FSC stakeholders to reveal valuable and critical data	S23	[53]

Technological Challenges	Tag	References
Architectural Design:		
BC design fragmentation	T1	[105], [87], [123]
Lack of sophistication in BC system design	T2	[24], [68], [129]
BC Trilemma: Hard to achieve decentralization, scalability and security at the same time	T3	[28], [45], [34], [85], [56], [119], [124]
Storage:		
BC not suitable for storing large amounts of data	T4	[47], [94], [83], [156], [158], [122], [129], [138], [140], [141], [141], [153], [154], [166]
Storage capacity scaling issues	T5	[42], [63], [60], [48], [49], [38], [36], [76], [81], [103], [82], [89], [110], [38], [46]
Complexity:		
System complexity	T6	[30], [105], [82], [54], [112], [17], [150]
Maintenance of the different BCs that arise	T7	[38]
Current interfaces for BC are too complex	T8	[78], [107], [117], [120]
Connectivity:		
Wireless connectivity limitations	T9	[97], [105], [114], [116], [122], [150]
Issues with Internet connections may occur	T10	[49], [109], [126], [127]
Interference due to the number of devices	T11	[102]
Unclear performance of Decode-and-Forward (DF) relays in BC enabled wireless networks for sustainable e-agriculture	T12	[102]
Insufficient communication protocols	T13	[105], [165]
Consensus Algorithms:		
Current consensus mechanisms require a wealth of computational resources, therefore limiting the BC network's scalability potential	T14	[26], [119], [124]
Consensus algorithm efficiency issues in IoT BC-based networks	T15	[29], [154], [126],
Optimising consensus mechanisms to deal with the numerous nodes and resources of public platforms	T16	[36]
Power consumption issues because of the consensus algorithms	T17	[89], [109] , [46], [156], [140], [147]
Coordination with other Technologies:		
Small amount of developed technological applications and gadgets that can be used in BC technologies	T18	[43], [87]
Lack of technological coordination between devices	T19	[43], [105], [107]
Need for integration with Cloud and Edge-centric architectures (e.g. IoT at the field)	T20	[30], [50], [36], [109]
BC-based IoT networks may be limited by IoT devices (e.g. low computational power and storage capacity)	T21	[55], [133], [135], [144], [153]
Data issues:		
Live monitoring of data is not possible	T22	[103], [109], [50]
Storage of more complex data than numbers and strings (like videos, photos) is not possible	T23	[50], [93], [103]
Inventing mechanisms to automatically verify the correctness of data entered to the BC transaction database	T24	[101], [121]
Non-existence of integrated information in BC-based systems	T25	[66]
Standardised information structures	T26	[47]

TABLE 11. Challenges for implementing BC technology in the agricultural sector (Part 3).

Technological Challenges (continued)	Tag	References
Interoperability:		
Poor Interoperability and Lack of Standardization	T27	[38], [80], [68], [98], [72], [100], [101], [105], [89], [110], [82], [55], [140], [141], [142]
Limited applicability of BC in FSC, because all differently developed BC systems need to cooperate between them	T28	[47], [94], [39], [51], [52], [78], [156], [121], [160]
Integration of BC with legacy systems	T29	[89], [50], [121]
Lack of technological standards in key sectors such as programming languages, data exchange etc.	T30	[74], [101], [52], [83], [84], [134]
Machine Learning:		
Further developments in information processing theory can provide insight into behavioural patterns of BC-based Supply-Chains	T31	[50]
Performance:		
Performance issues since each node in a BC needs to store all transactional history of the network	T32	[35]
Need for real time transactions with acceptable transaction time	T33	[75], [30], [26], [45], [52], [46]
High computational speed is needed in order to guarantee all transactions stored in a BC are done properly	T34	[65], [55], [109], [138], [145]
Eliminate need for miners and transaction fees	T35	[30], [64], [82], [105], [89], [110], [54], [115]
The faster the throughput (blocktime) is, the more centralised the network needs to be	T36	[71]
IoT and BC applications are taxing on performance, as IoT generates large volumes of data	T37	[36], [156]
Cryptographic verification, consensus mechanisms and redundancy processes per transaction slow down BC networks in comparison with traditional centralised ledgers	T38	[89], [71], [91], [156], [145]
Latency and Throughput issues	T39	[33], [65], [89], [105], [55], [36], [25], [83], [113], [115], [118], [120], [122], [129], [130], [145], [148], [164]
Scalability:		
Scalability Issues	T40	[62], [64], [59], [93], [61], [97], [65], [48], [24], [80], [38], [68], [98], [36], [71], [72], [74], [101], [51], [76], [77], [78], [31], [81], [32], [104], [46], [82], [105], [85], [87], [109], [118], [158], [140], [141], [142], [163], [164], [169]
BC limits the different transaction scenarios a system can handle	T41	[58]
BC technologies may have too much data to be shared, hence, the BC networks won't handle them properly	T42	[47], [93], [91], [99], [100], [50]
Scalability issues due to the large number of participating nodes	T43	[29], [23], [64], [24], [105]
Scalability harder to achieve when BC is integrated with data intensive technology, such as IoT	T44	[73]
Smart Contracts:		
Smart contacts must become accessible / applicable	T45	[67], [139], [153]
Standardised templates of smart contracts to address issues and assignments of a legal nature	T46	[101]
Develop methods to assess the semantic trustworthiness of smart contracts between interacting parties	T47	[101]
Automatic refund processes for farming insurances	T48	[30]
Updating and correcting smart contract code without impacting the BC network	T49	[101]
Need for automated payments and proof of delivery of crops	T50	[39], [25]
Miscellaneous:		
Lack of consistent technical terminology	T51	[80], [153]
Deeper traceability of products	T52	[98]
BC Forking	T53	[83]
Immutability doesn't allow for any corrections	T54	[84]
Individualization of products	T55	[107], [109], [162]
BC application in community sponsored agriculture	T56	[84], [108]
Different requirements of technology adoption for each stage of the FSC	T57	[85]
BC incapacity to monitor objectively all food quality parameters	T58	[87]

Environmental Challenges	Tag	References
Negative environmental impact due to large energy consumption	En1	[93], [38], [69], [99], [81], [103], [46], [59], [34], [24], [63], [82], [105], [89], [110], [109], [45], [115], [133], [135]
Negative environmental impacts due to BC implementation (large implementations, complexity, equipment)	En2	[93], [99], [41]

TABLE 12. Challenges for implementing BC technology in the agricultural sector (Part 4).

Legal Challenges	Tag	References
Standardization:		
General lack of standards about the BC	L1	[38], [101], [82], [62], [65], [119], [112], [129], [17], [167]
Lack of standards for data encryption	L2	[48], [78]
Lack of standards for data transmission	L3	[48], [49], [105], [89], [106]
Lack of data management standards	L4	[82], [105], [89], [110], [107], [80], [54]
Standardisation issues related to data anonymity, transactional privacy, transparency and confidentiality	L5	[94], [62], [65], [38], [111], [132]
Legal framework adaptability	L6	[78]
Compatibility with existing standards	L7	[38], [101], [135]
Contracts:		
Contractual confidentiality	L8	[74]
Validity of smart contracts	L9	[38]
Formalization of agricultural insurance programs	L10	[109]
Capacity for dispute resolution and legal enforcement, and linkage between computational transaction and natural language	L11	[82]
Ownership - Certification - IP:		
Infrastructure ownership issues	L12	[105]
Primary realization of infrastructure and responsibilities	L13	[54]
Ownership of maintenance duty of the infrastructure	L14	[54]
Patent related issues	L15	[57]
Legitimate certification system	L16	[109]

Security Challenges	Tag	References
Cyber security threats and issues:		
Threats to the cyber security on BC and underlying technologies	Se1	[29], [92], [42], [62], [82], [64], [65], [80], [75], [44], [149], [137], [141], [145], [147], [150], [151], [152]
Brute-force encryption attacks	Se1.1	[81], [69]
Honest majority security model issue	Se1.2	[71]
Majority attacks (51 percent of computing power)	Se1.3	[74], [110], [88], [156], [119], [116]
Miscellaneous threats and attacks (e.g. self-mining assaults, active liveness assault and double spending attack)	Se1.4	[116], [115]
Data integrity and tampering because of cyber security threats	Se1.5	[105], [107], [85], [109], [24], [99], [30], [138], [141]
Quantum resilience	Se1.6	[55]
Vulnerabilities:		
Lack of authentication among the nodes of the BC network	Se2	[23], [109]
Poorly developed or maintained code is vulnerable to hacking attacks	Se3	[76]
End user errors - loss of keys	Se4	[82]
Problems and vulnerabilities within the usage of consensus algorithms	Se5	[63], [42], [38]
Smart Contracts and Security:		
Smart contracts are weak to hacking attacks, and the improvement of their security is a big challenge	Se6	[72]
Smart contracts on the BC cannot be modified after they are deployed, therefore compromising the network's security if their code is vulnerable	Se7	[25]
Smart contract technological immaturity; numerous security gaps	Se8	[25], [51]
Need for strong security analysis technologies for smart contracts in case they are compromised	Se9	[101]
Smart contracts vulnerabilities (such as re-entrance bugs, callstack attacks, concurrency bugs and time dependency)	Se10	[25], [101], [161]
Privacy:		
Decentralisation contrary to anonymity in food traceability	Se11	[76], [55], [26], [99], [39], [72], [78], [106], [110], [153], [160]
Privacy information leakage and privacy threats	Se12	[36], [23], [29], [59], [30], [66], [101], [78], [82], [105], [142], [144], [148], [155], [169]
Implementing additional security mechanisms consumes energy	Se13	[109], [105]
Security issues of BC-based IoT networks:		
Security issues with BC-integrated technologies (e.g. IoT and sensors)	Se14	[101], [91], [81], [105], [85], [32]
Existence of cyber-threats	Se15	
Denial of Service (DoS)	Se15.1	[83], [88]
Sybil attacks	Se15.2	[83]
Eclipse Attack	Se15.3	[83]
Routing-Attacks	Se15.4	[83]
Miscellaneous:		
Need to secure both BCs and SCs	Se16	[55]
Accountability and auditability of trading and delivery of data	Se17	[25], [105], [86]
Serious threat for an organisation wide hit if BC's security fails	Se18	[39]

FIGURE 2. PESTELS analysis results.

Standardization of regulations regarding the BC and information sharing is first needed before adoption [76]. Towards this direction, different countries make steps, as indicated by the European Union with its BC strategy, supporting interoperability and relevant standards, envisaging a pan-European public services BC, and advancing towards a clear regulatory and legal regime [170], the US with their strategy for distributed ledger technology (DLT) [171], India with its national BC strategy [172], Australia with its BC roadmap [173] or China with its relevant guidelines [174]. All of them advance towards promoting BC in their markets, yet a unifying global policy and standardization still seem quite remote. Regulatory uncertainty can cause many unwanted complications [73]. One prominent complication of these is the unwanted constraining of smart contracts [52]. The "Data Act" [175] bill voted by the European Parliament, requires that all smart contracts contain a "kill switch". The switch can be used to terminate the contract at the will of the smart contract developer. While it can help in the event of a security breach or other emergency, it can also be used by a central authority to exact control over BC networks, reducing drastically decentralisation. Therefore, clear regulatory action that does not defeat the original purpose of employing BC is needed. Another need is the establishment of clear regulations around the type and quantity of data that can be published on a BC network [21]. Moreover, policies to protect user rights and trading secrets must be put in place [85]. Finally, proactive development of technology policies supporting necessary legal and market infrastructure and inclusive participation of value chain actors in the FSCs is needed [109].

c: BC'S DECENTRALIZED PARADIGM IS IN CONTRAST WITH GENERALLY CENTRALIZED GOVERNMENT MODELS (P6)

The philosophy behind BC is at odds with prevailing paradigms of government. BC is a decentralized system with no third party intervention, whereas the government classically relies on centralized authority [101]. Thus, BC forces changes in governance characteristics [82] and governmental regulations imposed on it reduce the value of its adoption [84].

d: PROVIDING INCENTIVES FOR INVOLVEMENT OF DECISION MAKERS FOR BC ADOPTION (P7)

According to Dey et al. [109], the potential of BC technology application in the execution of a BC-enabled commodity management platform is weakened by the absence of decision-maker buy-in in achieving efficiency, liquidity and data provenance. The absence of a precise verification tool for

FIGURE 3. Number of records mentioning at least one PESTELS challenge.

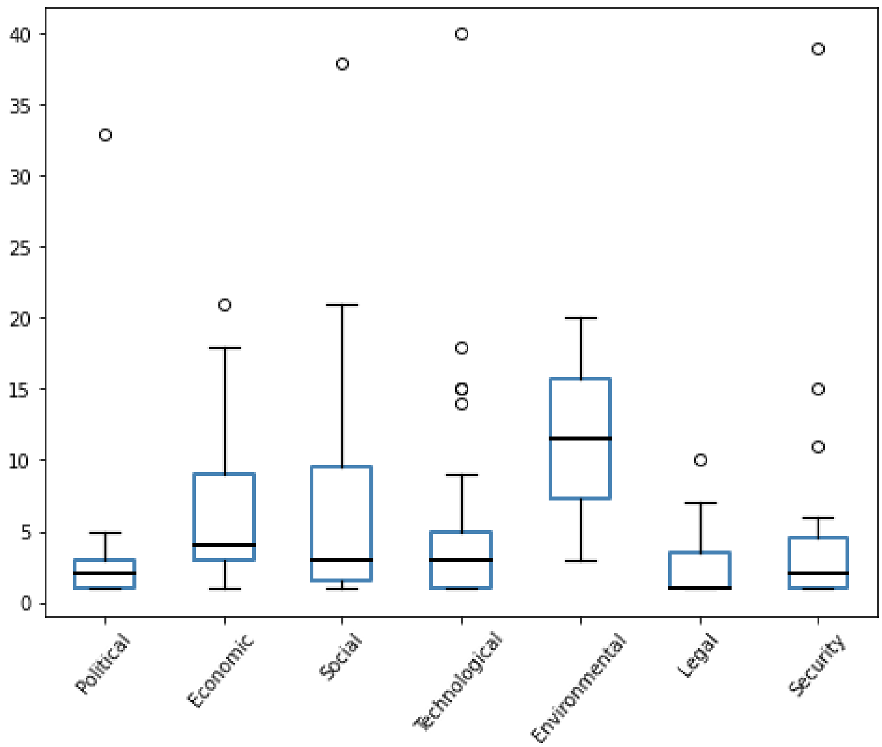

FIGURE 4. Distribution of challenge mentions along the PESTELS framework.

matching the physical and digital commodity, as well as the reduced connections between farmers and trading agencies, and the general lack of incentives, further debilitate BC's wider application.

e: THE INVOLVEMENT OF DIFFERENT COUNTRY REGULATORY AND LEGAL SYSTEMS MANDATES POLITICAL INTERVENTION (P8):

Chang et al. [78] mentioned that the determination of which laws apply to a BC system with nodes spread across many different countries is a complex task. Considering that, as of yet, there is a lack of governmental regulations, the scarcity of political intervention for the enactment of legal frameworks about the involvement of different countries in a BC network can be another barrier for adoption. In addition, Nagariya et al. [113] mentioned the abundance of regulatory issues with BC adoption in many different countries, while many of them, are not ready for its adoption.

f: NO AGREED ASSESSMENT OF BC AMONG GOVERNMENT AGENCIES IN DIFFERENT COUNTRIES (P9):

Even if countries cannot agree between them on a legal framework for the BC, they can at least work towards it by making a united effort to understand the technology. Governmental agencies internationally should assess the BC and agree on a common policy to follow regarding its emergence [57].

2) ECONOMIC CHALLENGES

a: BC RELATED COSTS (E1, E2, E3)

The implementation of BC incurs high costs for the individual stakeholders of the BC network [21], as well as for the companies who decide to digitalise their operations by using this technology. BC can also be very expensive in applications by small farmers [103]. Saberi et al. [50] and Cao et al. [96] also referred to the high implementation costs because of the new hardware and software that needs to be adopted. Ge et al. [38] discussed the high development cost in order to create a BC platform, while Morkunas et al. [52] referred to the costly specialized developers and the complex integration efforts. Lin et al. [39] argued about the costly and time-consuming challenges that exist in BC adoption. Zhao et al. [36] and Ge et al. [38] discussed the high costs for maintenance and upkeep of its operations. Two robust examples for this case were given by Antonucci et al. [54] and Rana et al. [99]. They referred to the highly expensive energy bills due to the high amount of computational power needed for the BC system to operate. Moreover, Catalini et al. [75] underlined the cost of maintaining a robust link between offline events and distributed ledger technology systems. Lezoche et al. [81] pointed out that BC technology implementations offer solutions which most of the time require crucial changes in existing technological equipment and, in some cases, its complete replacement. Ge et al. [38] argued that the replacement of existing technologies with new ones, requires time, money and effort. Hang et al. [23] mentioned that the replacement of existing technological equipment will also waste time and resources. Hence, the company's productivity towards consumer's needs may be reduced for a period of time, as well as new potential initiatives and actualization of more important business tasks may become standby. Therefore, the transition and the implementation of BC should be carefully strategised by the management of the company.

b: BC ECONOMIC OUTCOMES (E4, E5)

This section, refers to the possible negative economic outcomes after BC is implemented. Firstly, the implementation of BC technology has unclear economic benefits [44] and certainly incurs many economic risks for a company [105]. Secondly, Chang et al. [78] referred to the undetermined clear return of investment (RoI) that this technology can provide. Hence, the importance of carefully being aware about the advantages and the disadvantages before implementing BC in each use-case is definitely crucial. This matter was also discussed by Wang and You [150], who gave a reference to the topic of the unknown return by implementing BC technology. To go on, Lin et al. [39] suggested that the application of BC technology should be done carefully, and only after an in-depth research on the potential costs and risks has been carried out. Furthermore, according to Demestichas et al. [89] and Patelli et al. [69], an issue that can affect BC adoption is the high cost of the BC network for product traceability. In precise, these two articles argued that the overall high cost of BC-enabled traceability could exceed the product's own cost.

c: NEED FOR INVESTMENTS, INCENTIVES AND NEW ECONOMIC MODELS (E6, E7, E8, E9)

Gunasekera et al. [77] discussed the importance of demonstrating the positive effects of BC technology. In precise, they proposed that the public sector initiates investments in education and training, as well as in research and innovation, so as to produce evidence of its benefits. Education and training can be a hard matter to handle, as Liu et al. [79] referred to the overall lack of willingness that surrounds BC technology implementations. Moreover, Liu et al. [79] mentioned the lack of contract incentive strategies between the various BC stakeholders. While BC is referred to as costly, its implementation may not be affordable by everyone [48], and especially by small-farmers [80] and the developing world [69]. Defining new economic models to be applied in FSC and relative BC infrastructure, is also another challenge that can occur in the future, according to Antonucci et al. [54].

3) SOCIAL CHALLENGES

a: HESITANCE DUE TO TECHNOLOGICAL IMMATURITY AND OTHER BARRIERS (S1, S2)

In most records that were reviewed for this work, the technology of BC is described as an immature technology which is still in a very early stage of development. The lack of successful implementation cases [39] as well as the emerging stage of BC [89], are some factors that can negatively impact its reputation. In precise, Mistry et al. [88] and Wamba et al. [90], referred to the relatively new stage of this technology, its unclear remains, and the dilemma that can occur for its adoption. Saberi et al. [50] referred to the resistance and hesitation from individuals and organisations about its implementation. According to Katsikouli et al. [94], companies delay the adoption until BC use becomes a standardised collective initiative. Similarly, Jabbar et al. [101] mentioned that many potential BC stakeholders are waiting for a wider adoption before committing to it. Xiong et al. [70] referred to the possible lack of access for small farmers to the required infrastructures in order to participate in a decentralised BC-based system. Lezoche et al. [81] mentioned that implementation of BC can be done only when access to the Internet is available, something which cannot be taken for granted in the developing world. Demestichas et al. [89] and Zheng et al. [157] hint at the general lack of accessibility to BC technology, and the existence of technological gaps between first-world countries and undeveloped nations. This exact issue was also mentioned by Tiwari et al. [87], who argued about the digital division between the developing and the developed world.

b: LACK OF KNOWLEDGE, TECHNICAL AWARENESS, AND SKILLS (S3, S4, S5, S6, S7, S8)

An important social factor that can delay the adoption of the BC is the general lack of sophistication and skills about this technology that can come from companies, developers, or final consumers of the BC system. Saberi et al. [50] and Lezoche et al. [81] mentioned the limited technical expertise and knowledge on BC, while Nurgazina et al. [105] and Tiwari et al. [87] referred to the limited number of related training and education platforms. Duan et al. [85] referred to the lack of deeper understanding of BC by the companies; in precise, the full-scale consideration of both its benefits and dark-points. Moreover, the majority of farmers and producers are unaware of BC, its operations and its market potential [82], as well as the economic implications surrounding its adoption [110]. Pearson et al. [48] and Kim et al. [40] discussed the lack of business governance and management sophistication mechanisms by a company in order to implement BC. Another important challenging factor for the implementation of BC, stated by Nurgazina et al. [105] and Bodhke et al. [119], is the existence of human errors, e.g. in the development or the maintenance of the system's operation.

c: COLLABORATION AND TRUST (S9, S10)

Fu et al. [74] and Xiong et al. [70], highlighted the importance of collaboration between all involved parties in the FSC network as well as the need for their active attitude. According to Lin et al. [39], issues may occur with changing the outlook of all stakeholders involved in a BC system. In order to adopt BC, a drastic change in their age-old mindsets, work methodologies and general culture, needs to occur. Honesty, integrity and open-mindness are required, as stated by Tsang et al. [26]. For example, Nagariya et al. [113] mentioned that companies fear that shared data in a BC network can be hacked or lost, or can even be used from competitors to gain insights. Xu et al. [65] referred to the possible lack of trust that can exist between consumers and producers. An obvious reason for this is that the buyers of the final products can not be fully sure that the descriptions provided by the sellers are correct [31].

d: PERCEPTION AND ACCEPTANCE OF BC (S11, S12, S13)

The general acceptance of BC technology by society can also affect its use in agriculture. Saberi et al. [50] gave a characteristic example about this case. They mentioned that the existing association with cryptocurrencies, primarily slows down its adoption in general. In addition, BC's potential use in the agricultural sector surely generates a lot of queries that haven't been answered yet. Some of them are the actual effectiveness of BC systems for agricultural use [82], whether it can prevent a food-fraud issue or not [38], or even questioning its capability of bringing sustainability improvements in FSCs [110]. Moreover, Petersen et al. [44] and Li et al. [110] mentioned the general lack of BC acceptance in the industry. Furthermore, Ge et al. [38] mentioned that BC can also be considered as a potential threat to current business models. Lin et al. [39] mentioned that there is a perception that BC implementation might lead to loss of jobs, due to the possible replacement of human hands with technological equipment. Finally, as Nurgazina et al. [105] pointed out, there is a resistance to open information sharing within the agricultural sector. Many producers and SC mediators prefer not to share publicly any information regarding their trade, as it's possible that shocking or even outlawed practices might be revealed to the public.

e: SOCIETAL AND MARKET ISSUES (S14, S15, S16)

In terms of BC implementation in agriculture, market acceptability issues [101] and potential customer's behaviour ambiguity issues [50] may also arise. Customers may not be willing to pay more for the traceable products and also, most of them are unaware of the BC's potential benefits. As stated by Montecchi et al. [53], there is also the perspective that food provenance systems, like the BC, might cause fatigue to consumers by exposing them to an overwhelming amount of information.

f: SECTORAL AND COMPANY BARRIERS (S17, S18, S19, S20)

As long as the agricultural sector operates under pressure, the most valuable decisions for the modernization of a company's operations may never be taken [89]. Issues can also be raised from different stakeholders and their conflicting objectives [39]. Moreover, BC might eliminate inter-mediators, who are involved at the various stages of the FSC, leading to the creation of rifts in the SC [39]. Finally, Lin et al. [39] referred to the long-established perspective that the majority of problems can be handled by the use of traditional databases, and hence, the use of BC systems becomes underrated.

g: ETHICS AND DATA ISSUES (S21, S22, S23)

Bumblauskas et al. [63] and Creydt et al. [49] referred to the possible corrupted data that may be inserted to the BC due to human errors or even dishonest acts from the stakeholders of the network. The process of determining altered inputs, is insufficient and difficult [159]. For example, Griffin et al. [97] mentioned a potential scenario where individual stakeholders along the SC try to cheat the BC system by inserting corrupt data to it. Moreover, there is also the ethical issue of the unclear use of data inserted in the BC. Unclear use of data sharing and information handling was referred by Reyna et al. [42]. According to Patelli et al. [69], companies might also manipulate the data in order to perform consumer profiling, while Montecchi et al. [53] referred to the fact that valuable and critical information, which a company might prefer to keep secret, could be exposed to the public by a malicious participant in the BC network.

4) TECHNOLOGICAL CHALLENGES

a: ARCHITECTURAL DESIGN (T1, T2, T3)

As stated by Yadav et al. [68], there is a lack of sophisticated design for BC systems. Currently, many different architectures have been developed, providing a wide heterogeneity of solutions to a given problem [105]. Kramer et al. [24] argued that the wrong design choice, can lead to performance issues. Tiwari [87] mentioned that the design decisions of a BC system might reduce its overall flexibility. An important matter in any BC application is the in-feasibility of concurrently reconciling all three of the following traits: scalability, security and decentralization. This conundrum is also known as "the BC trilemma" [28], [56], [85]. In general, architectures of BC in agriculture shift to multi-chain paradigms, which have higher scalability potential, and desert single-chain structures [123].

b: STORAGE (T4, T5)

Katsikouli et al. [94], Casino et al. [55] and Torky et al. [83], stated that BC technology is not suitable for storing vast amounts of data. Considering that in large-scale networks, such as the agricultural SCs, where every participant should have a copy of all previous transactions, the maintenance of all these copies will soon lead to storage capacity issues [63]. Li et al. [110] also stated that these kinds of issues could lead to the decrease of the network's efficiency. Node synchronisation to join the network could be compromised by the growing needs for data storage [156]. Eventually, storage issues can be addressed by upgrading and furthering research procedures in the sector of storage capacity and scalability of BC technology, as per Reyna et al. [42].

c: COMPLEXITY (T6, T7, T8)

This category involves both hardware and software complexity [105], [150], as well as the application of the technology which can generally be complex and hard [54]. Ge et al. [38] discussed the complexity issues that can arise within the maintenance of the different BC networks. Stakeholders, and especially farmers, cannot cope with the complexity of BC technology's interfaces [78], and when this is coupled with the digitization of services related to customers [107], BC's adoption is hampered even more.

d: CONNECTIVITY (T9, T10, T11, T12, T13)

Griffin et al. [97] mentioned the wireless connectivity limitations between BC systems and its devices. Song and Li [102] referred to the example of interference transmission issues because of the many smart devices in the BC-enabled wireless networks. Rehman, A. et al., [116] mentioned connectivity issues arising due to the environment e.g. multipath effect and background noise. Creydt et al. [49] also discussed the possible issues within the Internet connections that may occur. Unfortunately, there is no guarantee about the continuous Internet connection of the BC system, and especially in rural areas and the developing world, while many factors can interrupt it. Moreover, in BC-based wireless networks made for promoting sustainable e-agriculture, the exact performance of DF relays is still unclear [102]. Finally, another problem regarding connectivity, is the insufficient communication protocols that can be used in BC systems and merged technologies like IoT [105].

e: CONSENSUS ALGORITHMS (T14, T15, T16, T17)

Ferrag et al. [29] referred to the efficiency issues in IoT BC-based networks that can come to light because of the consensus algorithms. In precise, this may happen due to the lack of computational power inherent in IoT devices, as well as their limited storage capacity. Low computing power means higher latency during block validation and limited storage means incapacity to hold all transaction records required in a BC network. The need for more effective consensus mechanisms is a problem that must be addressed in order to find a sustainable implementation for the BC [36]. In precise, lightweight structure algorithms, relying on parallelism to maximise throughput need to be deployed in low-powered IoT applications that need strict conservation of battery and minimal storage capacity [119]. Moreover, Zhao et al. [36] referred to this need for better consensus mechanisms that deal effectively with large amounts of nodes and resources stored in public service platforms. Consensus mechanisms require competition for computational resources, therefore, the network's potential to scale to more ambitious use cases becomes limited [26]. Finally, Demestichas et al. [89], Dey et al. [109] and Leng et al. [46], mentioned that the high computational demands of consensus algorithms, and especially of PoW algorithm, will result in high amounts of energy consumption.

f: COORDINATION WITH OTHER TECHNOLOGIES (T18, T19, T20, T21)

As of yet, there is only a small number of developed technological applications and gadgets that can be used in concert with BC systems. These include barcodes, IoT, Radio Frequency Veryfication (RFID) and Electronic Data Interchange (EDI) [43], [81]. There also might be a lack of technological coordination between the existing technological devices of the BC network [43], as well as the always present matter of the unreliability of data provided by sensors used in the system. Danese et al. [27] and Khalil et al. [153] referred to the problem of the limitation of BC use because of low computational power and storage capabilities of the IoT devices connected to the system. A small step towards the complete fulfillment of an integrated BC system could be done by the integration with cloud and edge-centric architectures [30]. Saberi et al. [50] also mentioned the need for improvement in storage management and the use of advanced cloud-computing infrastructures, while Dey et al. [109] proposed the integration of BC with IoT applications for backward and forward linkages in the e-agriculture sector.

g: DATA ISSUES (T22, T23, T24, T25, T26)

BC lacks access to technology that gets real-time information [50]. Durrant et al. [93], Debauche, O. et al. [103] mentioned that more complex types of data than strings and numbers, like photos and videos, are not supported. Jabbar et al. [101] mentioned the need to develop mechanisms for the verification of the correctness of data entered in the BC's transaction repository. Finally, more importance should be given to the development of integrated information BC-based systems [66], as they could further ease the adoption and diffusion of BC.

h: INTEROPERABILITY (T27, T28, T29, T30)

As mentioned in numerous records that we examined for this review, poor interoperability and lack of standardisation is an important factor hindering the BC's wide use [38], [68], [80], [98], [72], [142]. Interoperability is the quality of a technological tool, to easily communicate and exchange data with other tools based on the same technology. Interoperability of BC-based agricultural tools is a mandatory trait, if the BC is to know wider adoption. Most BC-based FSC approaches are limited in the scope of applicability due to their poor interoperability [47], as well as the wide variety of crops the BC is required to cover [114]. Yadav et al. [68] stated that the standardization of the multiple efforts taken in silos and the various developments of BC systems, as well as the assurance of their smooth interoperability is a must. Chang et al. [78] and Hughes et al. [51] also suggested that the allowance of different BC networks to share information together, requires strong standards and efforts in the subject of interoperability. Another big challenge for BC will be achieving cooperation and seamless integration with legacy traceability systems [89]. Many organisations have relied on their own management systems for years and it is complex and risky to redesign their entire systems around an emerging and unstable technology such as BC [73]. This instability is expressed through BC's lack of uniform standards in various technological sectors such as: communication mechanisms, application programming interfaces, programming languages, information security, transaction specifications, and data exchange. For example, a variety of contemporary BC platforms, such as Ethereum and Ripple, have poor compatibility and interoperability [74]. While multi-chain solutions can restore BC's scalability, they lack on the interoperability front even more than normal single-chain BC architectures. Therefore, they require the use of collaborative standardization regarding authentication, encryption algorithms, authorizations and consensus protocols, in order to achieve a satisfying level of interoperability [83].

i: MACHINE LEARNING (T31)

Further advancement in information processing theory supported by advanced ML methods could help in evaluating the phenomena and nuances of a wide and complex FSC. This understanding could ease the transition of the FSC from traditional technologies to a BC-based network [50].

j: PERFORMANCE (T32, T33, T34, T35, T36, T37, T38, T39)

According to Mao et al. [35] there might be performance issues since each node in a BC network needs to store the entire history of the BC. Moreover, a widely used FSC traceability system needs the capacity to support real time transactions, with a transaction speed comparable to traditional centralized networks [75]. Xu et al. [65] suggested that there is a need for high computational speed to guarantee that all transactions are stored properly in a BC network, which until now, is likely not feasible. Furthermore, the additional processes per transaction like the cryptographic verification, the high block-generation time, and the consensus mechanisms, slow down the BC networks in comparison with traditional centralized ledgers [71]. These performance-based issues are particularly accentuated during increased traffic [115] and lead to the major problem of increased latency [25], [89], [105], [145]. Casino et al. [55] mentioned that private BCs, compared to public ones, could be more efficient in terms of latency and transaction speed, but still, many issues may arise. Xu et al. [65] proposed the usage of 5G technology as a solution to this matter, which can be challenging and impractical for remote areas and the developing world. Nevertheless, the performance and the computational procedures of the BC could possibly improve in the case of the enactment of lightweight computation and the elimination of high transaction fees [30] as well as the reduction of block-generating time [71].

k: SCALABILITY (T40, T41, T42, T43, T44)

Scalability is one of the most mentioned barriers across the body of literature that was reviewed for this paper. The scalability of a technology, is its potential to be scaled enough to meet the requirements of various challenges, bigger or smaller. A complex agricultural SC is a large-scale challenge. Scaling the BC to satisfy the needs of an agricultural SC where the transactions are much more frequent than BC's current use-case in cryptocurrencies, will be a difficult barrier to overcome. As argued by Casino et al. [100], a multi-tier FSC network would require the processing of a large number of transactions in a relatively short period, something traditional BCs fail to cope with. Li et al. [58] mentioned that due to BC's low scalability potential, the trading transaction scenarios it can handle are limited. Furthermore, when BC technology is directly applied to the tracking and data storage of agricultural products, it is difficult to automatically store and retrieve the hash data stored in batches in the BC-based on identification. A solution suggested in multiple works would be to use a hybrid approach, such as using a private BC network to store transaction details, and only store the hashes of those blocks in a public BC. Moreover, integration of BC with data intensive technology such as IoT in a large-scale project, has the consequence of considerably lowering the throughput when compared to that of conventional centralized databases [73].

l: SMART CONTRACTS (T45, T46, T47, T48, T49, T50)

A first step towards resolving the issues that exist with smart contracts, would be to make them more accessible and applicable to farmers, and generally, to all the stakeholders [67]. Jabbar et al. [101] also stated that the development of standardised templates of smart contracts for various legal issues and assignments, would not only ease the BC adoption, but also the possibility of updating smart contracts with correct code without impacting the running network. Furthermore, there is a need to develop techniques for assessing the semantic trustworthiness of smart contracts between interacting parties [101]. Desirable features of smart contract technology should be the ability to force bad behaving actors to adhere to the terms of a contract (by removing them from the value chain) and the ability to solve disagreements when establishing the terms of the smart contract [139]. Smart contracts can be the medium that delivers security of transactions to both farmers and insurance providers for automating the refund process [30]. Apart from insurance, automated payments can be applied in other sectors as well; for example automated payments upon physical delivery of crops, both parties exchange cryptocurrency through the fulfillment of a smart contract [25], [39].

m: LACK OF CONSISTENT TECHNICAL TERMINOLOGY (T51)

Another challenge mentioned is the lack of consistent technical terminology regarding BC technology. Many publications use widely different terms. For example, they use ''Distributed Ledger'' instead of ''Blockchain'', or even attribute different meanings to the terms ''Blockchain'' and ''the Blockchain'' [80].

n: DEEPER TRACEABILITY OF PRODUCTS (T52)

Even deeper traceability. Tracing the finished product not only to its origin of raw materials, but also to the types and quantities of fertilisers and pesticides used [98].

o: BC FORKING (T53)

Another challenge is BC forking. BC forking is a common technical problem within BC networks, and it occurs when two peers (i.e. miners) add two right blocks to the chain at the same time [83].

p: IMMUTABILITY DOESN'T ALLOW FOR ANY CORRECTIONS (T54)

The immutability of BC does not allow for any corrections when errors in data entry are committed [84].

q: INDIVIDUALIZATION OF PRODUCTS (T55)

Product individualization by attributing a digital identity to the product and matching the physical product to the digital one, as well as its integration into other systems [107], [109].

r: BC APPLICATION IN COMMUNITY SPONSORED AGRICULTURE (T56)

In the case of community sponsored agriculture, BC could address authority, distribution and shareholding, and could be used as a general management tool, as it ensures transparency between producer and consumer, as well as making transactions between them completely independent from third parties [84], [108].

s: DIFFERENT REQUIREMENTS OF TECHNOLOGY ADOPTION FOR EACH STAGE OF THE FSC (T57)

Another challenge for the implementation of BC technology corresponds to the polymorphic nature of the FSC. Different stages of the SC have different requirements of technology adoption [85]. Some stages may require different data formats or sensor input, and the challenge lies in making a coherent BC tool that includes solutions for every different level of a product's SC.

t: BC INCAPACITY TO MONITOR OBJECTIVELY ALL FOOD QUALITY PARAMETERS (T58)

According to Tiwari [87], some food parameters cannot be objectively measured, especially those related to environmental indicators.

5) ENVIRONMENTAL CHALLENGES

Overall Environmental Challenges (En1, En2): The adoption of BC technologies may raise energy usage and consumption concerns [63]. These types of platforms demand a high amount of energy [41], [133] and can cause negative environmental impacts due to the block mining in the BC network [38]. In particular, Patelli et al. [69] discussed the PoW consensus algorithm which is highly consumptive during the mining process. Many of the articles that we analysed suggested the usage of PoS instead, which is meant to consume less computational resources and hence, less energy. All in all, the increased energy consumption can result in the emission of greenhouse gasses, furthering the environmental impact of the BC network [99]. Considering also the lack of sustainable mechanisms in a BC system [45], the negative environmental effect that can be caused because of the operations of a BC system makes its adoption a dilemma.

6) LEGAL CHALLENGES

a: STANDARDIZATION (L1, L2, L3, L4, L5, L6, L7)

To start with, Ge et al. [38] and Vangala et al. [62] referred to the general lack of standards about this technology. Jabbar et al. [101] mentioned the need to define a standardized framework for smart contracts in order to make them a fully automated process. Pearson et al. [48] discussed the lack of global standards about data encryption. Another standard-related issue is the data anonymity and data privacy problems [65], as well as the transactional transparency and confidentiality within the stakeholders of the BC network [62]. Katsikouli et al. [94] argued that maintaining data in a shared cloud platform to which every stakeholder has access, introduces a number of legal and trust-related consequences. Demestichas et al. [89] referred to the lack of data usage, management, and data sharing standardizations. Furthermore, according to Chang et al. [78] there is a need for BC's legal frameworks to be adaptable and reflect technological developments. Furthermore, Ge et al. [38] mentioned the need for BC's compatibility with already existing standards, while Ayed et al. [135] referred to the existence of complex legal frameworks. For example, the General Data Protection Regulation (GDPR) in European Law imposes the right for retroactive erasure of personal data from all distributed copies upon request, something which is infeasible in BC, because it keeps records of all transactions [101].

b: CONTRACTS (L8, L9, L10, L11)

Fu et al. [74] stated that the balance of confidentiality and transparency would need to be worked out. Since all of the information is accessible by all stakeholders, several contracts between organisations would need to be secured for some level of confidentiality to be retained. Ge et al. [38] mentioned the need for the validation and consistency of smart contracts. [109] referred to the demand of formalization of agricultural insurance programs throughout smart contracts. Upadhyay [82] discussed the linking of computational transactions to natural language contracts and the capacity for dispute resolution and legal enforcement.

c: OWNERSHIP – CERTIFICATION – IP (L12, L13, L14, L15, L16)

According to Nurgazina et al. [105] there might occur infrastructure ownership issues. Antonucci et al. [54] mentioned the ownership of the infrastructure's maintenance duties, as well as the primary realization of infrastructure and responsibilities with the different smart contracts. Drobyazko et al. [57] referred to patent related issues, such as the surge in patent disputes which can be devastating for the development of the technology. Finally, Dey et al. [38] stated that the development of a legitimate food certification system to work cooperatively with BC regulations is another important challenge for adoption.

7) SECURITY CHALLENGES

a: CYBER SECURITY THREATS AND ISSUES (Se1, Se1.1, Se1.2, Se1.3, Se1.4, Se1.5, Se1.6)

Firstly, the overall BC system, just like any other Information and Communication Technology (ICT) system, can be the subject of a wide range of cyber security threats [29]. A serious threat to a BC network, is when someone masters more than the 51 percent of the computing power of the entire network. In that case, data on the BC can be tampered with and forged [74] The 51% threat while not being common in large public BC networks, it can pose a real threat to the agricultural application of BC as networks are more often private, or contain a very small number of nodes and, therefore, attaining control of the majority of computational resources is feasible. A common threat to BC networks is the Double-spending Attack. This attack consists of a transaction between a malicious party paying a victim party to perform a service or buy a product. The malicious party, before the first transaction is confirmed by the network, immediately makes the same transaction by copying the currency that it used for the first transaction. Therefore the victim provides twice the service or product for only being paid once. In an agricultural BC, it can be used to hamper the network and possibly corrupt the BC itself [115]. Furthermore, another threat can result from a malicious minority percent of the validators permanently stalling the finalization process by publishing a block with missing data or interfering in general with the BC operation, opening it up to more attacks. This assault is called a self-mining assault [71], [116]. A third way to compromise the BC, is with the active liveness assault, an attack that can delay the confirmation time of a target transaction as much as possible [116]. Finally, brute-force decryption attacks always pose a significant threat on any BC-based database [81]. It is therefore apparent, that cyber-security attacks that grant access to tampering with data stored on the network, present a critical threat to adoption of BC-based databases [105]. An important security challenge of the future will also be the evaluation of the weaknesses of BC against quantum computers and the BC's general interaction with this emerging technology. Until nowadays, most BC networks use public key encryption algorithms. According to Casino et al. [55], the use of quantum computers is going to make them vulnerable to cyber-attacks. The only potential salvation will be the SHA-256 hash algorithm which will,still,have some security drawbacks against the quantum computers.

b: VULNERABILITIES (Se2, Se3, Se4, Se5)

One vulnerability of a BC system is the lack of authentication among the nodes of the BC network [23]. Also, according to Behnke et al. [76], the potential poorly developed or maintained code is vulnerable to hacking attacks. Another security issue that may arise in a BC system in both hardware and software aspects, is the end user's and stakeholder's errors that may happen. As an example, Upadhyay [82] mentioned the possible loss of keys. Furthermore, problems and vulnerabilities within the usage of the consensus algorithms of a BC network may arise as well [42]. Despite the energy-greedy and performance issues of their nature, the traditional consensus algorithms used in BC for data consistency in distributed networks can be problematic and even cause security issues. Bumblauskas et al. [63] suggested that instead, focusing on consensus between nodes in order to emphasize efficiency, speed, security, and fairness, should be better considered.

c: SMART CONTRACTS AND SECURITY (Se6, Se7, Se8, Se9, Se10)

Singh and Singh [72] referred to the weak nature of smart contracts and their potential vulnerabilities to hacking attacks. Shahid et al. [25] mentioned the immaturity of smart contracts and the possible security gaps such as insecure transactions [51]. Jabbar et al. [101] discussed the crucial matter of developing strong security analysis technologies for smart contracts in case they become compromised. Furthermore, Jabbar et al. [101] and Shahid et al. [25] referred to particular vulnerabilities such as re-entrancy bugs, time dependency, concurrency bugs and call-stack attacks. Finally, worth-noting is the fact that once a smart contract is deployed on the BC, then it cannot be modified and only executed as is. According to Shahid et al. [25], if its code is vulnerable it seriously affects the security of the whole BC network.

d: PRIVACY (Se11, Se12, Se13)

Privacy concerns present new challenges owing to the nature of BC. While stakeholders generally prefer to stay anonymous, BC's decentralized nature contradicts anonymity needs [26]. According to Chang et al. [78], finding the right balance between an individual's right to privacy and the degree of desired transparency is particularly challenging in cross-border BC applications. Moreover, privacy leakage and privacy threats are an important concern in this decentralized environment [23], [36]. For example, maintaining anonymity in IoT BC-based networks is not always certain, since it is possible for an attacker to infer the real identities of the IoT network's nodes by processing the publicly shared transactions between them [83]. Furthermore, Dey and Shekhawat [109] referred to the issues that can occur because of the implementation of extended security mechanisms in the BC network. In precise, they mentioned that the implementation of data security expends even more processing resources and energy. Hence, even environmental impact matters may additionally arise.

e: SECURITY ISSUES OF BC-BASED IOT NETWORKS: (Se14, Se15, Se15.1, Se15.2, Se15.3, Se15.4)

Jabbar et al. [101] referred to the security issues of the attached data-generating technologies like IoT, RFID and sensors. The integration of BC with an extensive peer-to-peer (P2P) wireless sensor network might give rise to several privacy and security issues in the whole agri-food value chain system [91]. Particularly, BC-based IoT networks are vulnerable to a variety of possible cyber-attacks [83]. These include the Denial of Service, the Sybil-Attacks, the Eclipse-Attacks and the Routing-Attacks. Denial of Service (DoS) is a type of cyber-attack in which the attacker tries to render the use of an IoT device unavailable to the authenticated users. In the Sybil-Attack scenario, the adversary sets up fake IoT nodes or sensors by duplicating their identities in order to set up fake connections in the BC-based IoT network. Eclipse-Attack is another attack that takes its name from the attempt of the attacker to obscure certain nodes from the rest of the P2P network so that they cannot receive data from any nodes other than the attacking ones. Finally, in the case of Routing-Attacks, the attacker intercepts and tampers with messages propagating between IoT devices. An intercepted message is filled with false information before it's sent back to the network's peers.

f: NEED TO SECURE BOTH BCS AND SCs (Se16)

As SCs operate as programs themselves, they frequently contain errors, and are prone to cyber-attacks. Therefore, research needs to be poured in how to secure SC itself, and how that security is maintained when the SC is migrated to a BC-based network [55].

g: ACCOUNTABILITY AND AUDITABILITY OF TRADING AND DELIVERY OF DATA (Se17)

Before the implementation of BC, the accountability and auditability of trading and delivery of data is also an issue that must be addressed [25]. Kamble et al. [84] argued that the permanence of records and the capability of sharing auditable information across the different stakeholders of the BC network must be ensured.

h: SERIOUS THREAT FOR AN ORGANISATION WIDE HIT IF BC's SECURITY FAILS (Se18)

The BC is a form of technology and none can guarantee its continual operation. Since a lot of factors could temporarily or permanently impact the system's functionalities and make it fail, the potential for organization-wide hit that can lead to unwanted consequences is a scenario that may occur [39].

B. DISCUSSION

The performed literature analysis answers quite extensively Research Question RQ1, classifying challenges for the application of BC in agriculture into seven categories following PESTELS framework typology. Open challenges are discerned into Political, Economical, Social, Technological, Environmental, Legal and Security, providing a good overview of the area under question.

Looking into the BC from the political point of view, it seems that a lot of effort has to be undertaken. Promoting a decentralized paradigm, BC is in contrast with generally centralized governance models. Spread among different countries of different legal systems mandates an assessment of the technology, before proceeding to standardization and conformance of legal and regulatory frameworks to promote its wider adoption in agrifood sector. Missing regulations, inappropriate decision maker interest, and lack of governmental support are all challenges that have to be looked into.

Several challenges exist from the economic point of view. High costs associated with the entire BC lifecycle starting from implementation of the needed infrastructure, development of adequate platforms and integration, to maintenance and upkeep, mandate careful planning at strategic level before its adoption. High computational power and energy costs, followed by not directly comprehensible benefits and undetermined RoI, mandate undertaking specific demonstration, education and training actions, to help potential users understand BC benefits. New economic models are necessary to deal with the need for new infrastructures and their maintenance that in the case of small farmers and developing countries is not possible to be undertaken by the agrifood sector alone.

From the social point of view, largely immature emerging BC technology, lacking sufficient implementations, and not being a standardised widely accepted and collectively participated paradigm creates hesitation and dilemmas to companies and farmers with reference to their participation. This hesitation is further enhanced by the digital divide that is present between urban and rural areas even in developed countries, let alone developing ones. Lack of knowledge about and deep understanding of the BC technology, as well as adequate skills, amplify resistance to change coming from the culture of the relatively conservative agrifood sector. Overall perception of the technology being associated primarily with cryptocurrencies does not create adequate acceptance, coupled by hesitance to change business models and fear for loss of jobs. With agrifood operating under pressure and consumers being unaware of BC benefits and unwilling to pay more for BC enabled product traceability, there is lack of necessary market maturity. Trust and ethics also raise important challenges with reference to data exposure and data manipulation in a BC enabled paradigm.

BC presents several technological challenges. Starting from its architecture, BC trilemma refers to the BC inability to address all together scalability, security and decentralization. Large scale agrifood applications need a processing of large numbers of transactions in short periods making scalability challenging. Technology complexity is high throughout BC lifecycle from implementation and deployment, to interfacing with the community and maintenance. Integration with other technologies is demanding at cloud and edge levels, as well as related to IoT. Performance issues arise due to the need to have entire history stored in each node, and processing of transactions slowing down the overall system, inducing high latency. Storage needs may lead to storage capacity issues. Connectivity issues appear due to limitations of IoT networking, wireless connectivity limitations and the digital divide for rural areas. Consensus algorithms lead to high computational demands, which is not always feasible, especially in the case of IoT sensor nodes. Lack of standardization leads to poor interoperability issues as well as integration with legacy systems. Semantic trustworthiness of smart contracts is also an issue hindering wide adoption of BC. Data issues appear with reference to real timeliness, verification, non support of complex data types, and incapacity of corrections even in the case of errors due to BC immutability principle. Deep traceability of products with reference to parameters like pesticides and fertilizers, as well as environmental indicators is difficult to be guaranteed. Machine Learning and 5G technologies could help address some of the BC technological challenges.

The main environmental challenge raised by the adoption of BC is associated with its high energy demand due to its consensus algorithms. Use of algorithms with less computational resource use and thus less energy consumption during the mining process, like PoS instead of PoW, is a suggestion.

Looking into BC from the legal perspective there is a lack of standardization with reference to the technology, the smart contracts framework, but also associated with data encryption, anonymity and privacy issues. There is a need to hit a balance between BC transparency and needed confidentiality at smart contract level, raising also issues of trust, validation and consistency of smart contracts, dispute resolution and legal enforcement. Need to comply with existing standards like GDPR, is quite difficult to meet due to BC immutability. Further legal challenges are associated with ownership of infrastructure, patents and certification issues.

Several security challenges rise related to BC adoption. BC can be subject to cyber security threats like majority attack, brute-force decryption and granting access to tampering. Existing vulnerabilities include lack of authentication, user errors, consensus algorithms, and poorly developed or maintained code causing hacking attacks. Immaturity and weak nature of Smart Contracts and their security gaps may lead to wider security issues for the system. Agrifood application of BC and use of data generating technologies like IoT pose further vulnerabilities like DoS, Sybil-Attacks, Eclipse-Attacks and Routing Attacks. A balance has to be stricken between transparency and privacy, while accountability and auditability of trading and delivery of data is an issue.

With reference to the Research Question RQ2 there seem to be a number of technology gaps related to the application of BC technology in general and in agriculture in particular. Starting from the design phase, there is a variety of architectures overall lacking a sophisticated design that could efficiently answer the BC trilemma: reconciling scalability, security and decentralization challenges. The nature of the agriculture sector as a large scale network mandates storage of vast amount of data leading to storage capacity issues. Complexity presents a further gap both for farmers and overall agricultural sector client base to efficiently deal with. Rural area connectivity issues also rise as an important gap, as ubiquitous connectivity that is a norm in urban areas remains a challenge for agriculture including IoT use and connectivity. Overall efficiency and performance issues rise with the use of IoT, generally characterised by low computational and storage resources, mandating more efficient consensus mechanisms. Poor interoperability and lack of standardisation and inconsistent technical terminology represent a further gap, overall affecting the agricultural sector operation in silos, raising issues of integration of enabling technologies, and data interoperability issues. Complexity and scalability also present a significant technology challenge and an open issue with complex agricultural SC being a large scale challenge. Application of smart contracts remains a challenging issue affecting security and semantic trustworthiness issues. Overall, security remains an issue to be efficiently dealt with comprising cyber security, privacy, accountability and auditability issues.

V. CONCLUSION

Overall, the present paper attempted to provide an overview of the state of the art for the application of BC technology to the agricultural sector. The PESTELS framework was used in order to classify challenges of the sector into seven categories. Analysis of the selected set of records provided answers to the two research questions examined related to the open challenges in the sector and the existing technology gaps. A summary for the findings for each category of the PESTELS framework is given in the following bullets:

- Political aspect: Agricultural use of BC will span continents, and while big countries and country coalitions have issued guidelines regarding BC, there is not a united initiative to address this rapidly advancing technology, halting its wide-spread application.
- Economic aspect: High costs of adoption and maintenance of new infrastructure. High cost of training personnel to use and maintain these infrastructures
- Social aspects: Common perception of BC as an immature technology, as well as its association with cryptocurrency does not permit its value to rise among stakeholders in the agricultural sector. Furthermore, the need it imposes on farmers to familiarise themselves with new concepts and tools puts another brake in BC adoption.
- Technological aspect: Difficult to reconcile scalability, security and decentralisation. Technological research is moving to multi-chain architectures to achieve scalability while retaining decentralisation. Scalability can also be addressed by more sophisticated consensus algorithms, but at the cost of security. Also, interoperability needs to be assured between different BC frameworks to achieve the level of diffusion needed for agricultural SC application, because of the complexity of the SCs.
- Environmental aspect: Concern about the environmental impact of widespread BC adoption as BC networks demand high energy expenditure.
- Legal aspect: Standardisation of legal procedures regarding BC is still a great impediment to adoption. There is not a general consensus on how to handle the novelties this technology brings to data ownership and privacy, automated contracts and infrastructure ownership.
- Security aspect: While BC is a generally secure technology, its relative novelty brings security concerns as all its potential is not explored fully yet. Smart contract security and BC-based IoT network security are two of the most important weaknesses to be addressed.

It is evident from the analysis of the challenges that the wider applicability of BC in the agricultural sector needs a number of actions at different levels and is a matter of the entire ecosystem. First and foremost research and academia should efficiently address technological and security challenges in order to increase the technology readiness level and boost its wider applicability. Secondly, securing funding is mandatory both for addressing BC related infrastructure and training costs and for the necessary research and innovation actions. The agrifood sector could present a short of "killer domain" for showcasing the merits and strengths of the BC technology and safeguarding the necessary funding both by the governments and the market. Thirdly, the active involvement of the policy makers and public administration is necessary in order to address political, and legal aspects pertaining to the BC technology adoption. Finally, there is a need for wider awareness raising that would promote the technological advantages presented. All above actions have the practical implication that an ecosystem activating approach is necessary in order for the BC technology to be actively promoted and widely adopted in the agricultural sector.

The area appears quite promising from the point of view of research effort needed to close the technology gaps and efficiently address the research challenges. Such effort can help increase the overall agricultural sector and relevant SC efficiency and performance with a significant outcome with reference to its overall competitiveness and enforcement of advanced business models. Despite the many challenges that exist, there seems to be room for optimism, as BC represents a technology with significant potential applicable in different and quite diverse sectors, just making its first steps in such a complex large-scale sector as the agricultural one. As maturity increases, it is expected that the existing challenges will be efficiently met, giving room to advancement in the field. Yet, there needs to be a coordinated action related to BC, so as to involve the entire Quadruple Helix of stakeholders, including policy makers and legislators, academia and research, businesses, SMEs and farmers, as well as the entire community and consumers, in an effort to increase awareness on BC benefits and offerings, as well as drawbacks and challenges. Adequate pilots should exhibit the merits of the new technology stirring the necessary market and consumer pull, and engaging policy makers in the necessary legal and regulatory interventions.

REFERENCES

[1] U. Desa, ''Transforming our world: The 2030 agenda for sustainable development,'' United Nations, Gen. Assem. New York, Tech. Rep. A/RES/70/1, 2016. [Online]. Available: https://daccess-ods.un.org/tmp/2871057.68918991.html

[2] M. D. Clercq, A. Vats, and A. Biel, ''Agriculture 4.0: The future of farming technology,'' in *Proc. World Government Summit*, 2018, pp. 11–13.

[3] D. F. Runde, C. Metzger, and H. F. Abdullah, *COVID-19 Demands Innovative Ideas for Financing the SDGs*. New York, NY, USA: JSTOR, 2020.

[4] M. Mukarram, ''Impact of COVID-19 on the UN sustainable development goals (SDGs),'' *Strategic Anal.*, vol. 44, no. 3, pp. 253–258, May 2020.

[5] C. Koulamas and A. Kalogeras, ''Cyber-physical systems and digital twins in the industrial Internet of Things [cyber-physical systems],'' *Computer*, vol. 51, no. 11, pp. 95–98, Nov. 2018.

[6] G. Mylonas, A. Kalogeras, G. Kalogeras, C. Anagnostopoulos, C. Alexakos, and L. Muñoz, ''Digital twins from smart manufacturing to smart cities: A survey,'' *IEEE Access*, vol. 9, pp. 143222–143249, 2021.

[7] H. Lasi, P. Fettke, H. G. Kemper, T. Feld, and M. Hoffmann, ''Industry 4.0,'' *Bus. Inf. Syst. Eng.*, vol. 6, no. 4, pp. 239–242, 2014.

[8] A. P. Fournaris, C. Alexakos, C. Anagnostopoulos, C. Koulamas, and A. Kalogeras, ''Introducing hardware-based intelligence and reconfigurability on industrial IoT edge nodes,'' *IEEE Des. Test*, vol. 36, no. 4, pp. 15–23, Aug. 2019.

[9] Y. Shiroishi, K. Uchiyama, and N. Suzuki, ''Society 5.0: For human security and well-being,'' *Computer*, vol. 51, no. 7, pp. 91–95, Jul. 2018.

[10] A. P. Kalogeras, H. Rivano, L. Ferrarini, C. Alexakos, O. Iova, S. Rastegarpour, and A. A. Mbacke, ''Cyber physical systems and Internet of Things: Emerging paradigms on smart cities,'' in *Proc. 1st Int. Conf. Societal Autom. (SA)*, Sep. 2019, pp. 1–13.

[11] M. Nofer, P. Gomber, O. Hinz, and D. Schiereck, ''Blockchain,'' *Bus. Inf. Syst. Eng.*, vol. 59, no. 3, pp. 183–187, 2017.

[12] S. Nakamoto, ''Bitcoin: A peer-to-peer electronic cash system,'' *Decentralized Bus. Rev.*, p. 8, 2008.

[13] J. A. Jaoude and R. G. Saade, ''Blockchain applications—Usage in different domains,'' *IEEE Access*, vol. 7, pp. 45360–45381, 2019.

[14] F. A. Sunny, P. Hajek, M. Munk, M. Z. Abedin, M. S. Satu, M. I. A. Efat, and M. J. Islam, ''A systematic review of blockchain applications,'' *IEEE Access*, vol. 10, pp. 59155–59177, 2022.

[15] F. Baumann, ''The next frontier—Human development and the anthropocene: UNDP human development report 2020,'' *Environment, Sci. Policy Sustain. Develop.*, vol. 63, no. 3, pp. 34–40, May 2021, doi: 10.1080/00139157.2021.1898908.

[16] B. Lashkari and P. Musilek, ''A comprehensive review of blockchain consensus mechanisms,'' *IEEE Access*, vol. 9, pp. 43620–43652, 2021.

[17] M. Alobid, S. Abujudeh, and I. Szűcs, ''The role of blockchain in revolutionizing the agricultural sector,'' *Sustainability*, vol. 14, no. 7, p. 4313, Apr. 2022. [Online]. Available: https://www.mdpi.com/2071-1050/14/7/4313

[18] L. Zhao, L. Chen, and A. Safi, ''Blockchain technology in post-COVID agriculture,'' in *Proc. 5th Int. Conf. Comput. Manage. Bus. (ICCMB)*, Jan. 2022, pp. 50–55, doi: 10.1145/3512676.3512685.

[19] A. Sendros, G. Drosatos, P. S. Efraimidis, and N. C. Tsirliganis, ''Blockchain applications in agriculture: A scoping review,'' *Appl. Sci.*, vol. 12, no. 16, p. 8061, Aug. 2022. [Online]. Available: https://www.mdpi.com/2076-3417/12/16/8061

[20] S. Stranieri, F. Riccardi, M. P. M. Meuwissen, and C. Soregaroli, ''Exploring the impact of blockchain on the performance of agri-food supply chains,'' *Food Control*, vol. 119, Jan. 2021, Art. no. 107495.

[21] J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, ''Future challenges on the use of blockchain for food traceability analysis,'' *TrAC Trends Anal. Chem.*, vol. 107, pp. 222–232, Oct. 2018.

[22] U. Sengupta and H. M. Kim, ''Meeting changing customer requirements in food and agriculture through the application of blockchain technology,'' *Frontiers Blockchain*, vol. 4, p. 5, Feb. 2021.

[23] L. Hang, I. Ullah, and D.-H. Kim, ''A secure fish farm platform based on blockchain for agriculture data integrity,'' *Comput. Electron. Agricult.*, vol. 170, Mar. 2020, Art. no. 105251.

[24] M. P. Kramer, L. Bitsch, and J. Hanf, ''Blockchain and its impacts on agri-food supply chain network management,'' *Sustainability*, vol. 13, no. 4, p. 2168, Feb. 2021.

[25] A. Shahid, A. Almogren, N. Javaid, F. A. Al-Zahrani, M. Zuair, and M. Alam, ''Blockchain-based agri-food supply chain: A complete solution,'' *IEEE Access*, vol. 8, pp. 69230–69243, 2020.

[26] Y. P. Tsang, K. L. Choy, C. H. Wu, G. T. S. Ho, and H. Y. Lam, ''Blockchain-driven IoT for food traceability with an integrated consensus mechanism,'' *IEEE Access*, vol. 7, pp. 129000–129017, 2019.

[27] P. Danese, R. Mocellin, and P. Romano, ''Designing blockchain systems to prevent counterfeiting in wine supply chains: A multiple-case study,'' *Int. J. Oper. Prod. Manage.*, vol. 41, no. 13, pp. 1–33, Dec. 2021.

[28] Y. Chen, Y. Li, and C. Li, ''Electronic agriculture, blockchain and digital agricultural democratization: Origin, theory and application,'' *J. Cleaner Prod.*, vol. 268, Sep. 2020, Art. no. 122071.

[29] M. A. Ferrag, L. Shu, X. Yang, A. Derhab, and L. Maglaras, ''Security and privacy for green IoT-based agriculture: Review, blockchain solutions, and challenges,'' *IEEE Access*, vol. 8, pp. 32031–32053, 2020.

[30] O. Lamtzidis, D. Pettas, and J. Gialelis, ''A novel combination of distributed ledger technologies on Internet of Things: Use case on precision agriculture,'' *Appl. Syst. Innov.*, vol. 2, no. 3, p. 30, Sep. 2019.

[31] I. E. Kyzy, H. Song, A. Vajdi, Y. Wang, and J. Zhou, ''Blockchain for consortium: A practical paradigm in agricultural supply chain system,'' *Expert Syst. Appl.*, vol. 184, Dec. 2021, Art. no. 115425.

[32] B. Bera, A. Vangala, A. K. Das, P. Lorenz, and M. K. Khan, ''Private blockchain-envisioned drones-assisted authentication scheme in IoT-enabled agricultural environment,'' *Comput. Standards Interface*, vol. 80, Mar. 2022, Art. no. 103567.

[33] O. Sushchenko and R. Schwarze, ''Distributed ledger technology for an improved index-based insurance in agriculture,'' *IDRiM J.*, vol. 10, no. 2, pp. 66–85, 2021.

[34] J. Bolt, ''Financial resilience of Kenyan smallholders affected by climate change, and the potential for blockchain technology,'' CCAFS, Rome, Italy, Tech. Rep. 549189, 2019.

[35] D. Mao, F. Wang, Z. Hao, and H. Li, ''Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain,'' *Int. J. Environ. Res. Public Health*, vol. 15, no. 8, p. 1627, Aug. 2018.

[36] G. Zhao, S. Liu, C. Lopez, H. Lu, S. Elgueta, H. Chen, and B. M. Boshkoska, ''Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions,'' *Comput. Ind.*, vol. 109, pp. 83–99, Aug. 2019.

[37] W. S. Alaloul, M. S. Liew, N. A. W. A. Zawawi, and I. B. Kennedy, ''Industrial revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders,'' *Ain Shams Eng. J.*, vol. 11, no. 1, pp. 225–230, Mar. 2020.

[38] L. Ge, C. Brewster, J. Spek, A. Smeenk, J. Top, F. van Diepen, B. Klaase, C. Graumans, and M. D. R. de Wildt, *Blockchain for Agriculture and Food: Findings From the Pilot Study*, no. 112. Wageningen, The Netherlands: Wageningen Economic Research, 2017.

[39] Y.-P. Lin, J. Petway, J. Anthony, H. Mukhtar, S.-W. Liao, C.-F. Chou, and Y.-F. Ho, ''Blockchain: The evolutionary next step for ICT E-agriculture,'' *Environments*, vol. 4, no. 3, p. 50, Jul. 2017.

[40] H. M. Kim and M. Laskowski, ''Agriculture on the blockchain: Sustainable solutions for food, farmers, and financing,'' in *Supply Chain Revolution, Barlow Books*, D. Tapscott, Ed., Toronto, ON, Canada, Dec. 2017. [Online]. Available: https://ssrn.com/abstract=3028164, doi: 10.2139/ssrn.3028164.

[41] R. Kamath, ''Food traceability on blockchain: Walmart's pork and mango pilots with IBM,'' *J. Brit. Blockchain Assoc.*, vol. 1, no. 2, p. 3712, 2018.

[42] A. Reyna, C. Martín, J. Chen, E. Soler, and M. Díaz, ''On blockchain and its integration with IoT. Challenges and opportunities,'' *Future Gener. Comput. Syst.*, vol. 88, pp. 173–190, Nov. 2018.

[43] B. Tan, J. Yan, S. Chen, and X. Liu, ''The impact of blockchain on food supply chain: The case of Walmart,'' in *Proc. Int. Conf. Smart Blockchain*. Cham, Switzerland: Springer, 2018, pp. 167–177.

[44] M. Petersen, N. Hackius, and B. von See, ''Mapping the sea of opportunities: Blockchain in supply chain and logistics,'' *IT Inf. Technol.*, vol. 60, nos. 5–6, pp. 263–271, Dec. 2018.

[45] G. Perboli, S. Musso, and M. Rosano, ''Blockchain in logistics and supply chain: A lean approach for designing real-world use cases,'' *IEEE Access*, vol. 6, pp. 62018–62028, 2018.

[46] K. Leng, Y. Bi, L. Jing, H.-C. Fu, and I. Van Nieuwenhuyse, ''Research on agricultural supply chain system with double chain architecture based on blockchain technology,'' *Future Gener. Comput. Syst.*, vol. 86, pp. 641–649, Sep. 2018.

[47] F. Casino, V. Kanakaris, T. K. Dasaklis, S. Moschuris, and N. P. Rachaniotis, ''Modeling food supply chain traceability based on blockchain technology,'' *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2728–2733, 2019.

[48] S. Pearson, D. May, G. Leontidis, M. Swainson, S. Brewer, L. Bidaut, J. G. Frey, G. Parr, R. Maull, and A. Zisman, "Are distributed ledger technologies the panacea for food traceability?" *Global Food Secur.*, vol. 20, pp. 145–149, Mar. 2019.

[49] M. Creydt and M. Fischer, "Blockchain and more–Algorithm driven food traceability," *Food Control*, vol. 105, pp. 45–51, Nov. 2019.

[50] S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, "Blockchain technology and its relationships to sustainable supply chain management," *Int. J. Prod. Res.*, vol. 57, no. 7, pp. 2117–2135, Apr. 2019.

[51] A. Hughes, A. Park, J. Kietzmann, and C. Archer-Brown, "Beyond Bitcoin: What blockchain and distributed ledger technologies mean for firms," *Bus. Horizons*, vol. 62, no. 3, pp. 273–281, May 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0007681319300023

[52] V. J. Morkunas, J. Paschen, and E. Boon, "How blockchain technologies impact your business model," *Bus. Horizons*, vol. 62, no. 3, pp. 295–306, May 2019.

[53] M. Montecchi, K. Plangger, and M. Etter, "It's real, trust me! Establishing supply chain provenance using blockchain," *Bus. Horizons*, vol. 62, no. 3, pp. 283–293, May 2019.

[54] F. Antonucci, S. Figorilli, C. Costa, F. Pallottino, L. Raso, and P. Menesatti, "A review on blockchain applications in the agri-food sector," *J. Sci. Food Agricult.*, vol. 99, no. 14, pp. 6129–6138, Nov. 2019.

[55] F. Casino, T. K. Dasaklis, and C. Patsakis, "A systematic literature review of blockchain-based applications: Current status, classification and open issues," *Telematics Informat.*, vol. 36, pp. 55–81, Mar. 2019.

[56] M. Peńa, J. Llivisaca, and L. Siguenza-Guzman, "Blockchain and its potential applications in food supply chain management in Ecuador," in *Proc. Int. Conf. Adv. Emerg. Trends Technol.* Cham, Switzerland: Springer, 2019, pp. 101–112.

[57] S. Drobyazko, V. Makedon, D. Zhuravlov, Y. Buglak, and V. Stetsenko, "Ethical, technological and patent aspects of technology blockchain distribution," *J. Legal, Ethical Regulatory Issues*, vol. 22, pp. 1–6, Jan. 2019.

[58] X. Li, D. Wang, and M. Li, "Convenience analysis of sustainable E-agriculture based on blockchain technology," *J. Cleaner Prod.*, vol. 271, Oct. 2020, Art. no. 122503.

[59] D. Roeck, H. Sternberg, and E. Hofmann, "Distributed ledger technology in supply chains: A transaction cost perspective," *Int. J. Prod. Res.*, vol. 58, no. 7, pp. 2124–2141, Apr. 2020.

[60] J. Tipmontian, J. C. Alcover, and M. Rajmohan, "Impact of blockchain adoption for safe food supply chain management through system dynamics approach from management perspectives in Thailand," *Proceedings*, vol. 39, no. 1, p. 14, 2020.

[61] R. Iqbal and T. A. Butt, "Safe farming as a service of blockchain-based supply chain management for improved transparency," *Cluster Comput.*, vol. 23, pp. 2139–2150, Sep. 2020.

[62] A. Vangala, A. K. Das, N. Kumar, and M. Alazab, "Smart secure sensing for IoT-based agriculture: Blockchain perspective," *IEEE Sensors J.*, vol. 21, no. 16, pp. 17591–17607, Aug. 2021.

[63] D. Bumblauskas, A. Mann, B. Dugan, and J. Rittmer, "A blockchain use case in food distribution: Do you know where your food has been?" *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 102008.

[64] S. V. Akram, P. K. Malik, R. Singh, G. Anita, and S. Tanwar, "Adoption of blockchain technology in various realms: Opportunities and challenges," *Secur. Privacy*, vol. 3, no. 5, p. e109, Sep. 2020.

[65] Y. Xu, X. Li, X. Zeng, J. Cao, and W. Jiang, "Application of blockchain technology in food safety control: Current trends and future prospects," *Crit. Rev. Food Sci. Nutrition*, vol. 62, no. 10, pp. 2800–2819, 2020.

[66] G. Mirabelli and V. Solina, "Blockchain and agricultural supply chains traceability: Research trends and future challenges," *Proc. Manuf.*, vol. 42, pp. 414–421, Jan. 2020.

[67] J. Frank, "Blockchain functionality: How smart contracts can save small farms," NYLS Legal Stud. Res. Paper 3662648, 2020, p. 22.

[68] V. S. Yadav, A. R. Singh, R. D. Raut, and U. H. Govindarajan, "Blockchain technology adoption barriers in the Indian agricultural supply chain: An integrated approach," *Resour., Conservation Recycling*, vol. 161, Oct. 2020, Art. no. 104877.

[69] N. Patelli and M. Mandrioli, "Blockchain technology and traceability in the agrifood industry," *J. Food Sci.*, vol. 85, no. 11, pp. 3670–3678, Nov. 2020.

[70] H. Xiong, T. Dalhaus, P. Wang, and J. Huang, "Blockchain technology for agriculture: Applications and rationale," *Frontiers Blockchain*, vol. 3, p. 7, Feb. 2020.

[71] P. Dutta, T.-M. Choi, S. Somani, and R. Butala, "Blockchain technology in supply chain operations: Applications, challenges and research opportunities," *Comput. Ind.*, vol. 109, pp. 83–99, 2020.

[72] P. Singh and D. Singh, "Blockchain with IoT and AI: A review of agriculture and healthcare," *Int. J. Appl. Evol. Comput.*, vol. 11, pp. 13–27, Oct. 2020.

[73] W. Lin, X. Huang, H. Fang, V. Wang, Y. Hua, J. Wang, H. Yin, D. Yi, and L. Yau, "Blockchain technology in current agricultural systems: From techniques to applications," *IEEE Access*, vol. 8, pp. 143920–143937, 2020.

[74] H. Fu, C. Zhao, C. Cheng, and H. Ma, "Blockchain-based agri-food supply chain management: Case study in China," *Int. Food Agribusiness Manage. Rev.*, vol. 23, pp. 1–14, Mar. 2020.

[75] J. S. Catalini and C. Gans, "Some Siple economics of the blockchain," *Commun. ACM*, vol. 63, no. 7, pp. 80–90, 2020.

[76] K. Behnke and M. F. W. H. A. Janssen, "Boundary conditions for traceability in food supply chains using blockchain technology," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 101969. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0268401219303536

[77] D. Gunasekera and E. Valenzuela, "Adoption of blockchain technology in the Australian grains trade: An assessment of potential economic effects," *Econ. Papers, A J. Appl. Econ. policy*, vol. 39, no. 2, pp. 152–161, Jun. 2020, doi: 10.1111/1759-3441.12274.

[78] Y. Chang, E. Iakovou, and W. Shi, "Blockchain in global supply chains and cross border trade: A critical synthesis of the state-of-the-art, challenges and opportunities," *Int. J. Prod. Res.*, vol. 58, no. 7, pp. 2082–2099, Apr. 2020.

[79] P. Liu, Y. Long, H.-C. Song, and Y.-D. He, "Investment decision and coordination of green agri-food supply chain considering information service based on blockchain and big data," *J. Cleaner Prod.*, vol. 277, Dec. 2020, Art. no. 123646.

[80] G. A. Motta, B. Tekinerdogan, and I. N. Athanasiadis, "Blockchain applications in the agri-food domain: The first wave," *Frontiers Blockchain*, vol. 3, p. 6, Feb. 2020.

[81] M. Lezoche, J. E. Hernandez, M. D. M. E. A. Díaz, H. Panetto, and J. Kacprzyk, "Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture," *Comput. Ind.*, vol. 117, May 2020, Art. no. 103187.

[82] N. Upadhyay, "Demystifying blockchain: A critical analysis of challenges, applications and opportunities," *Int. J. Inf. Manage.*, vol. 54, Oct. 2020, Art. no. 102120.

[83] M. Torky and A. E. Hassanein, "Integrating blockchain and the Internet of Things in precision agriculture: Analysis, opportunities, and challenges," *Comput. Electron. Agricult.*, vol. 178, Nov. 2020, Art. no. 105476.

[84] S. S. Kamble, A. Gunasekaran, and R. Sharma, "Modeling the blockchain enabled traceability in agriculture supply chain," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 101967.

[85] J. Duan, C. Zhang, Y. Gong, S. Brown, and Z. Li, "A content-analysis based literature review in blockchain adoption within food supply chain," *Int. J. Environ. Res. Public Health*, vol. 17, no. 5, p. 1784, Mar. 2020.

[86] S. S. Kamble, A. Gunasekaran, and S. A. Gawankar, "Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications," *Int. J. Prod. Econ.*, vol. 219, pp. 179–194, Jan. 2020.

[87] U. Tiwari, "Application of blockchain in agri-food supply chain," *Britain Int. Exact Sci. (BIoEx) J.*, vol. 2, no. 2, pp. 574–589, May 2020.

[88] I. Mistry, S. Tanwar, S. Tyagi, and N. Kumar, "Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenges," *Mech. Syst. Signal Process.*, vol. 135, Jan. 2020, Art. no. 106382.

[89] K. Demestichas, N. Peppes, T. Alexakis, and E. Adamopoulou, "Blockchain in agriculture traceability systems: A review," *Appl. Sci.*, vol. 10, no. 12, p. 4113, Jun. 2020.

[90] S. F. Wamba and M. M. Queiroz, "Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 102064.

[91] A. Rejeb, J. G. Keogh, S. Zailani, H. Treiblmaier, and K. Rejeb, "Blockchain technology in the food industry: A review of potentials, challenges and future research directions," *Logistics*, vol. 4, no. 4, p. 27, Oct. 2020.

[92] H. Chen, Z. Chen, F. Lin, and P. Zhuang, "Effective management for blockchain-based agri-food supply chains using deep reinforcement learning," *IEEE Access*, vol. 9, pp. 36008–36018, 2021.

[93] A. Durrant, M. Markovic, D. Matthews, D. May, G. Leontidis, and J. Enright, "How might technology rise to the challenge of data sharing in agri-food?" *Global Food Secur.*, vol. 28, Mar. 2021, Art. no. 100493.

[94] P. Katsikouli, A. S. Wilde, N. Dragoni, and H. Høgh-Jensen, "On the benefits and challenges of blockchains for managing food supply chains," *J. Sci. Food Agricult.*, vol. 101, no. 6, pp. 2175–2181, Apr. 2021.

[95] M. Verma, "Smart contract model for trust based agriculture using blockchain technology," *Int. J. Res. Anal. Rev.*, vol. 8, no. 2, pp. 354–355, 2021.

[96] S. Cao, W. Powell, M. Foth, V. Natanelov, T. Miller, and U. Dulleck, "Strengthening consumer trust in beef supply chain traceability with a blockchain-based human-machine reconcile mechanism," *Comput. Electron. Agricult.*, vol. 180, Jan. 2021, Art. no. 105886.

[97] T. W. Griffin, K. D. Harris, J. K. Ward, P. Goeringer, and J. A. Richard, "Three digital agriculture problems in cotton solved by distributed ledger technology," *Appl. Econ. Perspect. Policy*, vol. 44, no. 1, pp. 237–252, Mar. 2022.

[98] S. Saurabh and K. Dey, "Blockchain technology adoption, architecture, and sustainable agri-food supply chains," *J. Cleaner Prod.*, vol. 284, Feb. 2021, Art. no. 124731.

[99] R. L. Rana, C. Tricase, and L. D. Cesare, "Blockchain technology for a sustainable agri-food supply chain," *Brit. Food J.*, vol. 123, no. 11, pp. 3471–3485, Oct. 2021.

[100] F. Casino, V. Kanakaris, T. K. Dasaklis, S. Moschuris, S. Stachtiaris, M. Pagoni, and N. P. Rachaniotis, "Blockchain-based food supply chain traceability: A case study in the dairy sector," *Int. J. Prod. Res.*, vol. 59, no. 19, pp. 5758–5770, Oct. 2021, doi: 10.1080/00207543.2020.1789238.

[101] S. Jabbar, H. Lloyd, M. Hammoudeh, B. Adebisi, and U. Raza, "Blockchain-enabled supply chain: Analysis, challenges, and future directions," *Multimedia Syst.*, vol. 27, pp. 1–20, Aug. 2021.

[102] K. Song and C. Li, "Blockchain-enabled relay-aided wireless networks for sustainable e-agriculture," *J. Cleaner Prod.*, vol. 281, Jan. 2021, Art. no. 124496.

[103] O. Debauche, S. Mahmoudi, P. Manneback, and F. Lebeau, "Cloud and distributed architectures for data management in agriculture 4.0: Review and future trends," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 34, no. 9, pp. 7494–7514, Oct. 2022.

[104] T. Kassanuk and K. Phasinam, "Design of blockchain based smart agriculture framework to ensure safety and security," *Mater. Today, Proc.*, vol. 51, pp. 2313–2316, Jan. 2022.

[105] J. Nurgazina, U. Pakdeetrakulwong, T. Moser, and G. Reiner, "Distributed ledger technology applications in food supply chains: A review of challenges and future research directions," *Sustainability*, vol. 13, no. 8, p. 4206, Apr. 2021.

[106] M. W. Barbosa, "Uncovering research streams on agri-food supply chain management: A bibliometric study," *Global Food Secur.*, vol. 28, Mar. 2021, Art. no. 100517.

[107] M. H. Ronaghi, "A blockchain maturity model in agricultural supply chain," *Inf. Process. Agricult.*, vol. 8, no. 3, pp. 398–408, Sep. 2021.

[108] G. D. S. R. Rocha, L. de Oliveira, and E. Talamini, "Blockchain applications in agribusiness: A systematic review," *Future Internet*, vol. 13, no. 4, p. 95, Apr. 2021.

[109] K. Dey and U. Shekhawat, "Blockchain for sustainable e-agriculture: Literature review, architecture for data management, and implications," *J. Cleaner Prod.*, vol. 316, Sep. 2021, Art. no. 128254.

[110] K. Li, J.-Y. Lee, and A. Gharehgozli, "Blockchain in food supply chains: A literature review and synthesis analysis of platforms, benefits and challenges," *Int. J. Prod. Res.*, vol. 61, no. 11, pp. 3527–3546, 2021.

[111] T. Paul, N. Islam, S. Mondal, and S. Rakshit, "RFID-integrated blockchain-driven circular supply chain management: A system architecture for B2B tea industry," *Ind. Marketing Manage.*, vol. 101, pp. 238–257, Feb. 2022.

[112] A. Pakseresht, A. Yavari, S. A. Kaliji, and K. Hakelius, "The intersection of blockchain technology and circular economy in the agri-food sector," *Sustain. Prod. Consumption*, vol. 35, pp. 260–274, Jan. 2023.

[113] R. Nagariya, S. Mukherjee, M. M. Baral, B. S. Patel, and C. Venkataiah, "The challenges of blockchain technology adoption in the agro-based industries," *Int. J. Math., Eng. Manage. Sci.*, vol. 7, no. 6, pp. 949–963, Dec. 2022.

[114] S. Anand and A. Sharma, "Comprehensive analysis of services towards enhancing security in IoT-based agriculture," *Meas., Sensors*, vol. 24, Dec. 2022, Art. no. 100599.

[115] S. L. T. Vangipuram, S. P. Mohanty, E. Kougianos, and C. Ray, "AgroString: Visibility and provenance through a private blockchain platform for agricultural dispense towards consumers," *Sensors*, vol. 22, no. 21, p. 8227, Oct. 2022.

[116] A. Rehman, S. Abdullah, M. Fatima, M. W. Iqbal, K. A. Almarhabi, M. U. Ashraf, and S. Ali, "Ensuring security and energy efficiency of wireless sensor network by using blockchain," *Appl. Sci.*, vol. 12, no. 21, p. 10794, Oct. 2022.

[117] R. A. Ahmed, E. E. Hemdan, W. El-Shafai, Z. A. Ahmed, E. M. El-Rabaie, and F. E. A. El-Samie, "Climate-smart agriculture using intelligent techniques, blockchain and Internet of Things: Concepts, challenges, and opportunities," *Trans. Emerg. Telecommun. Technol.*, vol. 33, no. 11, Nov. 2022, Art. no. e4607.

[118] F. Sabrina, N. Li, and S. Sohail, "A blockchain based secure IoT system using device identity management," *Sensors*, vol. 22, no. 19, p. 7535, Oct. 2022.

[119] U. Bodkhe, S. Tanwar, P. Bhattacharya, and N. Kumar, "Blockchain for precision irrigation: Opportunities and challenges," *Trans. Emerg. Telecommun. Technol.*, vol. 33, no. 10, Oct. 2022, Art. no. e4059.

[120] P. Vijay, "Grainchain–agricultural supply chain traceability and management technique for farmers sustainability using blockchain hyper ledger," *Int. J. Intell. Syst. Appl. Eng.*, vol. 10, no. 3, pp. 141–146, 2022.

[121] L. B. Krithika, "Survey on the applications of blockchain in agriculture," *Agriculture*, vol. 12, no. 9, p. 1333, Aug. 2022.

[122] R. Chaganti, V. Varadarajan, V. S. Gorantla, T. R. Gadekallu, and V. Ravi, "Blockchain-based cloud-enabled security monitoring using Internet of Things in smart agriculture," *Future Internet*, vol. 14, no. 9, p. 250, Aug. 2022.

[123] X. Peng, X. Zhang, X. Wang, J. Xu, H. Li, Z. Zhao, and Z. Qi, "A refined supervision model of Rice supply chain based on multi-blockchain," *Foods*, vol. 11, no. 18, p. 2785, Sep. 2022.

[124] P. Bagga, A. K. Das, V. Chamola, and M. Guizani, "Blockchain-envisioned access control for Internet of Things applications: A comprehensive survey and future directions," *Telecommun. Syst.*, vol. 81, no. 1, pp. 125–173, Sep. 2022.

[125] Z. Luo, J. Zhu, T. Sun, Y. Liu, S. Ren, H. Tong, L. Yu, X. Fei, and K. Yin, "Application of the IoT in the food supply chain–from the perspective of carbon mitigation," *Environ. Sci. Technol.*, vol. 56, no. 15, pp. 10567–10576, Aug. 2022.

[126] I. G. Tende, K. Aburada, H. Yamaba, T. Katayama, and N. Okazaki, "Proposal for a blockchain based agricultural input voucher system," *Artif. Life Robot.*, vol. 27, no. 3, pp. 461–471, Aug. 2022.

[127] J. F. Wünsche and F. Fernqvist, "The potential of blockchain technology in the transition towards sustainable food systems," *Sustainability*, vol. 14, no. 13, p. 7739, Jun. 2022.

[128] L. Wang, C. Qi, P. Jiang, and S. Xiang, "The impact of blockchain application on the qualification rate and circulation efficiency of agricultural products: A simulation analysis with agent-based modelling," *Int. J. Environ. Res. Public Health*, vol. 19, no. 13, p. 7686, Jun. 2022.

[129] V. S. Yadav, A. R. Singh, R. D. Raut, S. K. Mangla, S. Luthra, and A. Kumar, "Exploring the application of industry 4.0 technologies in the agricultural food supply chain: A systematic literature review," *Comput. Ind. Eng.*, vol. 169, Jul. 2022, Art. no. 108304.

[130] A. Marchese and O. Tomarchio, "A blockchain-based system for agri-food supply chain traceability management," *Social Netw. Comput. Sci.*, vol. 3, no. 4, p. 279, May 2022.

[131] R. Seranmadevi, A. S. Kumar, and R. Hariharan, "Enabling agricultural sector through blockchain technology—Farmers perspective," *Universal J. Agricult. Res.*, vol. 10, no. 3, pp. 213–227, Jun. 2022.

[132] J. D. Borrero and J. Mariscal, "A case study of a digital data platform for the agricultural sector: A valuable decision support system for small farmers," *Agriculture*, vol. 12, no. 6, p. 767, May 2022.

[133] S. Wadhwa, S. Rani, S. Verma, J. Shafi, and M. Wozniak, "Energy efficient consensus approach of blockchain for IoT networks with edge computing," *Sensors*, vol. 22, no. 10, p. 3733, May 2022.

[134] N. N. Misra, Y. Dixit, A. Al-Mallahi, M. S. Bhullar, R. Upadhyay, and A. Martynenko, "IoT, big data, and artificial intelligence in agriculture and food industry," *IEEE Internet Things J.*, vol. 9, no. 9, pp. 6305–6324, May 2022.

[135] R. Ben Ayed, M. Hanana, S. Ercisli, R. Karunakaran, A. Rebai, and F. Moreau, "Integration of innovative technologies in the agri-food sector: The fundamentals and practical case of DNA-based traceability of olives from fruit to oil," *Plants*, vol. 11, no. 9, p. 1230, May 2022.
[136] H. H. Khan, M. N. Malik, Z. Konečná, A. G. Chofreh, F. A. Goni, and J. J. Klemeš, "Blockchain technology for agricultural supply chains during the COVID-19 pandemic: Benefits and cleaner solutions," *J. Cleaner Prod.*, vol. 347, May 2022, Art. no. 131268.
[137] J. Abijaude, P. Sobreira, L. Santiago, and F. Greve, "Improving data security with blockchain and Internet of Things in the gourmet cocoa bean fermentation process," *Sensors*, vol. 22, no. 8, p. 3029, Apr. 2022. [Online]. Available: https://www.mdpi.com/1424-8220/22/8/3029
[138] S. Dey, S. Saha, A. K. Singh, and K. McDonald-Maier, "SmartNoshWaste: Using blockchain, machine learning, cloud computing and QR code to reduce food waste in decentralized web 3.0 enabled smart cities," *Smart Cities*, vol. 5, no. 1, pp. 162–176, Feb. 2022.
[139] N. M. Lee, L. R. Varshney, H. C. Michelson, P. Goldsmith, and A. Davis, "Digital trust substitution technologies to support smallholder livelihoods in sub-Saharan Africa," *Global Food Secur.*, vol. 32, Mar. 2022, Art. no. 100604. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2211912421001127
[140] A. Alkhateeb, C. Catal, G. Kar, and A. Mishra, "Hybrid blockchain platforms for the Internet of Things (IoT): A systematic literature review," *Sensors*, vol. 22, no. 4, p. 1304, Feb. 2022.
[141] Z. Shah, I. Ullah, H. Li, A. Levula, and K. Khurshid, "Blockchain based solutions to mitigate distributed denial of service (DDoS) attacks in the Internet of Things (IoT): A survey," *Sensors*, vol. 22, no. 3, p. 1094, Jan. 2022.
[142] A. A. Khan, Z. A. Shaikh, L. Belinskaja, L. Baitenova, Y. Vlasova, Z. Gerzelieva, A. A. Laghari, A. A. Abro, and S. Barykin, "A blockchain and metaheuristic-enabled distributed architecture for smart agricultural analysis and ledger preservation solution: A collaborative approach," *Appl. Sci.*, vol. 12, no. 3, p. 1487, Jan. 2022.
[143] L. Song, Y. Luo, Z. Chang, C. Jin, and M. Nicolas, "Blockchain adoption in agricultural supply chain for better sustainability: A game theory perspective," *Sustainability*, vol. 14, no. 3, p. 1470, Jan. 2022.
[144] Z. Yu, L. Song, L. Jiang, and O. K. Sharafi, "Systematic literature review on the security challenges of blockchain in IoT-based smart cities," *Kybernetes*, vol. 51, no. 1, pp. 323–347, Jan. 2022.
[145] W. Yang, S. Wang, X. Yin, X. Wang, and J. Hu, "A review on security issues and solutions of the Internet of Drones," *IEEE Open J. Comput. Soc.*, vol. 3, pp. 96–110, 2022.
[146] A. Hassoun, F. Boukid, A. Pasqualone, C. J. Bryant, G. G. García, C. Parra-López, S. Jagtap, H. Trollman, J. Cropotova, and F. J. Barba, "Emerging trends in the agri-food sector: Digitalisation and shift to plant-based diets," *Current Res. Food Sci.*, vol. 5, pp. 2261–2269, 2022.
[147] K. Agrawal, M. Aggarwal, S. Tanwar, G. Sharma, P. N. Bokoro, and R. Sharma, "An extensive blockchain based applications survey: Tools, frameworks, opportunities, challenges and solutions," *IEEE Access*, vol. 10, pp. 116858–116906, 2022.
[148] A. El Mane, Y. Chihab, K. Tatane, and R. Korchiyne, "Agriculture supply chain management based on blockchain architecture and smart contracts," *Appl. Comput. Intell. Soft Comput.*, vol. 2022, pp. 1–23, Oct. 2022.
[149] R. P. Sahayaraj and M. Sannasy, "Decentralised and predictive system for efficient agri-transactions through blockchain technology," *Stud. Informat. Control*, vol. 31, no. 3, pp. 125–140, Sep. 2022.
[150] Y. Wang and J. You, "The operation mode of agricultural supply chain finance using blockchain," *Comput. Intell. Neurosci.*, vol. 2022, pp. 1–11, Sep. 2022.
[151] A. H. Adow, M. K. Shrivas, H. F. Mahdi, M. M. A. Zahra, D. Verma, N. V. Doohan, and A. Jalali, "Analysis of agriculture and food supply chain through blockchain and IoT with light weight cluster head," *Comput. Intell. Neurosci.*, vol. 2022, pp. 1–11, Aug. 2022.
[152] D.-H. Nguyen, N. Huynh-Tuong, and H.-A. Pham, "A blockchain-based framework for developing traceability applications towards sustainable agriculture in Vietnam," *Secur. Commun. Netw.*, vol. 2022, pp. 1–10, Jul. 2022.
[153] U. Khalil, O. A. Malik, and S. Hussain, "A blockchain footprint for authentication of IoT-enabled smart devices in smart cities: State-of-the-art advancements, challenges and future research directions," *IEEE Access*, vol. 10, pp. 76805–76823, 2022.
[154] J. Wang, "Application of IoT in exploring the development path of the whole agricultural industry chain under the perspective of ecological environment," *Mobile Inf. Syst.*, vol. 2022, pp. 1–11, Jun. 2022.
[155] S. Vyas, M. Shabaz, P. Pandit, L. R. Parvathy, and I. Ofori, "Integration of artificial intelligence and blockchain technology in healthcare and agriculture," *J. Food Qual.*, vol. 2022, pp. 1–11, May 2022.
[156] T. Rathod, N. Jadav, S. Tanwar, R. Sharma, A. Tolba, M. Raboaca, V. Marina, and W. Said, "Blockchain-driven intelligent scheme for IoT-based public safety system beyond 5G networks," *Sensors*, vol. 23, no. 2, p. 969, Jan. 2023.
[157] Y. Zheng, Y. Xu, and Z. Qiu, "Blockchain traceability adoption in agricultural supply chain coordination: An evolutionary game analysis," *Agriculture*, vol. 13, no. 1, p. 184, Jan. 2023.
[158] N. K. Jadav, T. Rathod, R. Gupta, S. Tanwar, N. Kumar, and A. Alkhayyat, "Blockchain and artificial intelligence-empowered smart agriculture framework for maximizing human life expectancy," *Comput. Electr. Eng.*, vol. 105, Jan. 2023, Art. no. 108486.
[159] C. Valencia-Payan, J. Grass-Ramíez, G. Ramirez-Gonzalez, and J. C. Corrales, "Smart contract to traceability of food social selling," *Comput., Mater. Continua*, vol. 74, no. 3, pp. 4703–4728, 2023.
[160] Z. Raza, I. U. Haq, and M. Muneeb, "Agri-4-all: A framework for blockchain based agricultural food supply chains in the era of fourth industrial revolution," *IEEE Access*, vol. 11, pp. 29851–29867, 2023.
[161] R. A. Mishra, A. Kalla, A. Braeken, and M. Liyanage, "Blockchain regulated verifiable and automatic key refreshment mechanism for IoT," *IEEE Access*, vol. 11, pp. 21758–21770, 2023.
[162] P. Saranya and R. Maheswari, "Proof of transaction (PoTx) based traceability system for an agriculture supply chain," *IEEE Access*, vol. 11, pp. 10623–10638, 2023.
[163] A. Vangala, A. K. Das, A. Mitra, S. K. Das, and Y. Park, "Blockchain-enabled authenticated key agreement scheme for mobile vehicles-assisted precision agricultural IoT networks," *IEEE Trans. Inf. Forensics Security*, vol. 18, pp. 904–919, 2023.
[164] Y. Chang, J. Xu, and K. Z. Ghafoor, "An IoT and blockchain approach for the smart water management system in agriculture," *Scalable Comput., Pract. Exper.*, vol. 22, no. 2, Oct. 2021, Art. no. e12892.
[165] T. Miller, S. Cao, M. Foth, X. Boyen, and W. Powell, "An asset-backed decentralised finance instrument for food supply chains—A case study from the livestock export industry," *Comput. Ind.*, vol. 147, May 2023, Art. no. 103863.
[166] R. Sharma and B. Villányi, "A sustainable Ethereum merge-based big-data gathering and dissemination in IIoT system," *Alexandria Eng. J.*, vol. 69, pp. 109–119, Apr. 2023.
[167] H. Patel and B. Shrimali, "AgriOnBlock: Secured data harvesting for agriculture sector using blockchain technology," *ICT Exp.*, vol. 9, no. 2, pp. 150–159, Apr. 2023.
[168] K. Chatterjee, A. Singh, and Neha, "A blockchain-enabled security framework for smart agriculture," *Comput. Electr. Eng.*, vol. 106, Mar. 2023, Art. no. 108594.
[169] F. Dal Mas, M. Massaro, V. Ndou, and E. Raguseo, "Blockchain technologies for sustainability in the agrifood sector: A literature review of academic research and business perspectives," *Technolog. Forecasting Social Change*, vol. 187, Feb. 2023, Art. no. 122155.
[170] (2023). *Blockchain Strategy*. [Online]. Available: https://digital-strategy.ec.europa.eu/en/policies/blockchain-strategy
[171] (2022). *U.S. Bill Proposes National Strategy for Blockchain*. DLT. [Online]. Available: https://www.ledgerinsights.com/u-s-bill-proposes-national-strategy-for-blockchain-dlt/
[172] D. P. Saxena. (2021). *National Strategy on Blockchain: A Step in Right Direction and Timely Too*. [Online]. Available: https://www.psa.gov.in/article/national-strategy-blockchain-step-right-direction-and-timely-too/3495
[173] (2021). *Australia's Blockchain Roadmap*. [Online]. Available: https://www.dfat.gov.au/about-us/publications/trade-and-investment/business-envoy-april-2021-digital-trade-edition/australias-blockchain-roadmap
[174] I. Hong. (2021). *China Sets Goal to be Blockchain World Leader by 2025*. [Online]. Available: https://www.asiafinancial.com/china-sets-goal-to-be-blockchain-world-leader-by-2025
[175] European Commission. (2022). *Proposal for a Regulation of the European Parliament and of the Council on Harmonised Rules on Fair Access to and Use of Data (Data Act)*. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0068

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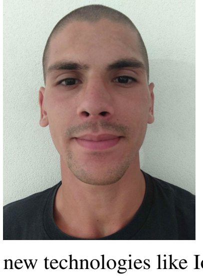

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