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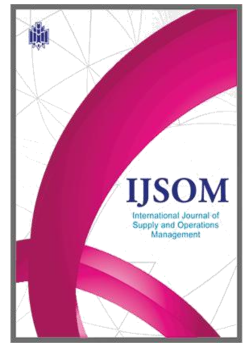

Application of Blockchain Disruptive Technology in Agri-Food Chains for Sustainable Development, a Systematic Review

Luighi Cruz [a*] and Paulo Sergio De Arruda Ignacio [a]

[a] *Faculty of Sciences Applied, CENPRO, University of Campinas, Brazil*

Abstract

The importance of applying disruptive technologies to improve the efficiency of different processes within the agri-food chain for sustainable development is increasing day by day. In the current scenario, agri-food chains face disruptions caused by the consequences of COVID-19 or the War in Ukraine, resulting in reduced quality, availability, transparency, trust, and security of different food products within the distribution chain. This paper aims to map the convergence between the use of Blockchain technology for sustainable development and agri-food chains. The specific objectives are pointing to key co-occurrence networks and clusters, mapping the emerging thematic axes from the literature, showcasing key authors and journals, and organizing the collected data based on economic, social, and environmental (three pillars of sustainability). The research design is organized using Systematic Review Methodology. The originality of this review includes the verification of data performance through bibliometric and the organization and analysis of the identified articles based on the dimensions of sustainability. The findings show that the adoption and use of Blockchain technology improve supply chain sustainability performance and point to a developing trend in the area under study. There is a high concentration of theoretical contributions, with the environmental dimension being less addressed. A detailed analysis of the findings is presented to provide a comprehensive and up-to-date view of agri-food chains, Blockchain, and sustainable development. Furthermore, this work offers research opportunities to develop new research based on Blockchain and sustainable development.

Keywords: Agricultural; Sustainable Development Goals; Supply Chain; Distributed Ledger.

Introduction

It is undeniable that agriculture and agri-food chains are undergoing changes promoted by the application of technologies, as a result, cutting-edge technologies contribute to the improvement of food management (Chandan et al., 2023; M. Kumar et al., 2023)**.** Food is a basic necessity of humanity, and prior to the COVID-19 pandemic and the Ukraine War, 135 million people suffered from acute hunger (Tyagi, 2023)**.** Currently, due to the Ukraine crisis, there is a scarcity of food among the world's poorest populations (ONU, 2023).

In view of this, in the near future, agriculture and food systems will be characterized by radical and revolutionary technological applications (Klerkx & Rose, 2020). Thus, the implementation of emerging technologies in agriculture allows for the emergence of e-agriculture or agriculture 4.0, reducing costs and labor (Jararweh et al., 2023; Leduc et al., 2021), which yields above normal production rates at a rate of 200 to 400% (Davies & Garrett, 2018) with the aim of meeting the projected need to produce up to 60% more food by 2050 (Benyam et al., 2021). Consequently, it is understood that current production levels have better performance than those of the past.

*Corresponding author email address: L229493@dac.unicamp.br
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On the other hand, different initiatives have been carried out around the world to strengthen sustainable development. Sustainability is conceived as growth that satisfies current wants without endangering the capability of next generations to provide for themselves. (Brundtland & ONU 1987). Under this reasoning, the Sustainable Development Goals known as SDGs were defined, which address the global problems that humanity faces, including environmental concerns, inequality, and poverty, especially related to the most vulnerable and disadvantaged populations within the current economic paradigm, aiming to build a sustainable future (Quayson et al., 2021).

Furthermore, perishable products managed throughout the agri-food chain require special treatment. In this regard, there are those with a fixed shelf life and products with continuous decomposition (Aazami & Saidi-Mehrabad, 2021)**.** For instance, products with fixed shelf-life expiration dates, such as medications or packaged goods, while products with continuous decomposition experience a gradual decline in quality over time. Consequently, the faster the delivery to the end customer, the better the margins and benefits for the entire chain (Hashemi-Amiri et al., 2023)**.**

Regarding global agri-food chains, between 25 and 30 percent of the food produced each year for human use is wasted, or nearly 1,300 billion tonnes of food, which comprises 30% of cereals, between 40 and 50% of pereshibles, and oilseeds, 20% of meat, and 35% of maritime products (FAO, 2021). Then, a study of 228 countries and territories to assess their capacity to confront the challenges of agricultural degradation products shown an increase of 35% in malnourished people for the year 2021, or almost 768 million people (Institute for Economics & Peace, 2022). Thus, loss factors may be poor resource management and inefficient supply chain processes, and unsustainable consumption patterns (Anastasiadis et al., 2022). In this sense, some authors comment on the possibility of food crises strengthened by water, energy, and climate scarcity or by other factors related to high demographic growth rates and social progress that do not feed sustainably.

Furthermore, the COVID-19 pandemic tested the flexibility of supply chains in different sectors, allowing for the discovery and consideration of new variables or inputs for various fields of study. Thus, many structures and chains were affected by centralizing operations in chains with greater flexibility and changing consumer behavior from "in-person" shopping to "online" shopping, assuming risks of choosing clean, safe, and quality agricultural output (Kazancoglu et al., 2023; Nguyen et al., 2022).

Likewise, new agri-food chain business models are progressively expanding based on digitization (Mercuri et al., 2021), within which some economic and ethical practices are not addressed. For example, farmers are at the mercy of commercial structures that put pressure on weaker prices (Sodamin et al., 2022), and the high number of intermediaries or actors does not allow for fair information and negotiation visibility (Bager et al., 2022; Quayson et al., 2021), considering that nearly 56% of businesses worldwide suffer severe disruptions in the supply chain (Rashid et al., 2022). In contrast, the food sector requires greater support and improved government policies to enhance sustainable practices from an economic, political, and social perspective (Chandan et al., 2023)**.**

Given the foregoing, the biggest issue is making the transition from knowledge-based agriculture to data-driven smart agriculture (Scuderi et al., 2022), and because blockchain technology is decentralized, open, and transparent, it can be applied to agriculture with outstanding benefits. (Song et al., 2022).

Under this spectrum, it is known that the application of Blockchain in agri-food chains has been studied since approximately 2015, as observed in the different existing research within the scientific community. However, different studies show that there is still no consensus on all the benefits of a decentralized flow of information, as the application of Blockchain is accepted in some studies while in others, significant improvements of this technology are expected in the long term for its subsequent application. Thus, post-application results guarantee that Blockchain technology is sustainable or contributes to the sustainability of the chain (Dey & Shekhawat, 2021; Fernandez-Vazquez et al., 2022; Friedman & Ormiston, 2022; Kamble et al., 2020; Mao et al., 2018; Rashid et al., 2022; Saurabh & Dey, 2021; Yousefi & Mohamadpour Tosarkani, 2022). With this, the following research question is made: Is there a convergence between sustainable development and the use of blockchain technology in agri-food chains?

Therefore, even with the use of blockchain, there is no assurance that ongoing procedures and profits will be either ineffective or unsustainable. Considering all of the above, the primary objective of this paper is to show how sustainable development and the use of Blockchain technology in agri-food chains intersect. The specific objectives are pointing to key co-occurrence networks and clusters, mapping the emerging thematic axes from the literature, showcasing key authors and journals, and organizing the collected data based on economic, social, and environmental sustainability, which are its three pillars.

In summary, this paper is organized as follows: section 2 presents the theoretical framework, section 3 presents the research methodology, section 4 highlights the results, section 5 shows the managerial implications and practical insights, and finally section 6 concludes the research with conclusions, limitations, and future works.

Literature background

Disruptive Technology Blockchain

Blockchain is a decentralized data ledger. It is also considered a pivotal technology for replacing traditional methods of storing, organizing, and sharing agricultural data in a decentralized, transparent, reliable, and immutable way (Torky & Hassanein, 2020; Peepliwal, et al., 2022). Disruptive technology allows for a complete change in the conventional mode of production, offering a profound change in traditional processes.

Furthermore, the literature indicates that the application of Blockchain offers a series of benefits and advantages for agri-food chains, such as traceability, decentralization, immutability of records, transparency, and smart contracts (Dos Santos et al., 2021; Munir et al., 2022). Smart contracts are understood as computer protocols that facilitate the verification, execution, and obligations of the terms of commercial agreements (Saurabh & Dey, 2021), receiving transactions that are executed by programmed functions receiving any produced information (Salah et al., 2019a). Thus, smart contracts enabled by Blockchain technology can significantly increase supply chain management efficiency (Wamba & Queiroz, 2020), and exclude third parties from contract execution, making transactions faster, more flexible, cost-effective, irreversible, and traceable (Saurabh & Dey, 2021). Smart contracts also solve the problem of sensitive data manipulation (Dutta et al., 2020; Salah et al., 2019a), due to the immutable nature of the blockchain network, as shown in Figure 1.

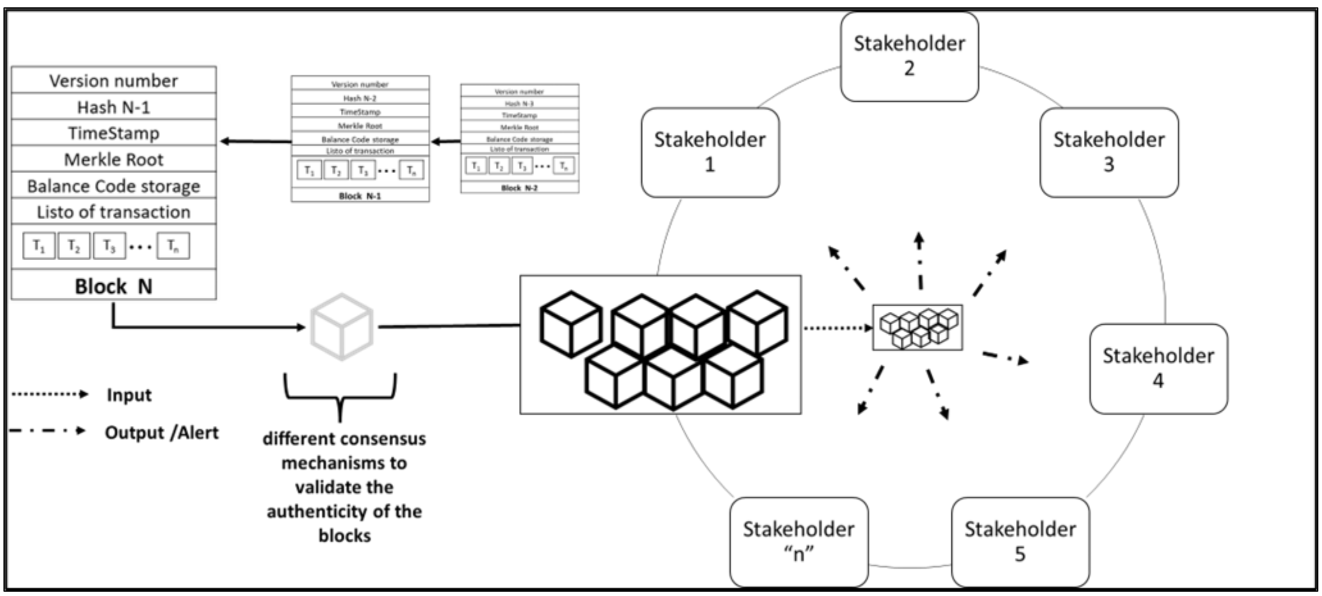

Figure 1. Operation of Blockchain

In addition, the functioning of the Blockchain network is based on different consensus mechanisms to validate the authenticity of the blocks that will be added to the network, as shown in Figure 1. In this sense, the proposed and constantly updated consensus mechanisms are: Proof of Work, Proof of Stake, Proof of Authority, and Proof of Elapsed Time (Torky & Hassanein, 2020; J. Zhang et al., 2022). The new block is evaluated and inserted into the network, and then all nodes in the network are notified and alerted (Chain stakeholders), considering that the sent information becomes immutable and decentralized. In the following process, the network miners, after using the consensus mechanism and adding the block to the Blockchain network, receive compensation, making the network free of excessive intermediaries and reducing operating costs.

Blockchain technology's use in the agri-food supply chain for sustainable development

Agricultural Supply Chain manages the entire chain from production to delivery of the product to the end customer. Thus, the food supply chain is characterized by the participation of different actors that include: suppliers, producers, distributors, other intermediaries, and customers (Niknejad et al., 2021), with a high level of complexity, the need for digitization is paramount (Dutta et al., 2020). In addition, traditional agri-food chains by nature present food waste within operations. Ironically, many of them are rotting in different containers around the world (Sodamin et al., 2022), and another frequent form of food loss is qualitative waste, meaning that the attributes of the food are reduced, making it inedible (without nutritional value) (Vangala et al., 2021). In contrast, an agri-food chain with practices based on economy, society, and the environment can be considered a green chain (Jararweh et al., 2023)**.**

In parallel, growing threats such as food insecurity and contamination demand a revolutionary traceability system that ensures sufficient security for food distribution (Hang et al., 2020), indeed, as it is well-known, many chains are difficult to trace due to their extensive nature (Tyagi, 2023). Thus, recent scandals worldwide have demonstrated that there is no reliable, transparent, and decentralized system applied in the management of the agro-industrial chain (Khan et al., 2020). Additionally, the pandemic has provided lessons learned, for example, real-time information is essential, coordination must be decentralized, and bureaucratic processes reduced for the flexibility of the agri-food chain (Pincheira et al., 2021). Numerous studies aim to close the gap between areas for improvement and the adoption of new technologies in the agri-food supply chain as a result of these factors.

Subsequently, as mentioned, it’s the willingness of future generations to meet their own needs without sacrificing their capacity to meet current or future requirements is known as sustainable development., i.e., it enables efforts to build a sustainable future. Thus, the dimensions of Sustainable Development - social (people and communities), environmental (environmental impact), and economic (benefit and income) - are evaluated and considered to achieve sustainability, where each dimension is a necessary condition (Andersson et al., 2022b; Njualem and Ogundare, 2023).

Regarding the social dimension, it is necessary to overcome problems such as fraud, human rights violations, environmental contamination, visibility, food waste, centralization, and others. In view of this, the application of Blockchain creates shared value, improves food traceability, decentralizes information, makes unknown actors visible, drives environmental sustainability, and offers security for all types of products (Bager et al., 2022; Friedman & Ormiston, 2022; Oguntegbe et al., 2021; Quayson et al., 2021). Similarly, certifications required by public agencies or issued by third parties can be simplified with the application of Blockchain, thus avoiding misleading advertising and reducing resource consumption (Dos Santos et al., 2021). At the same time, government policies, the impacts of public actions, consumer attitudes towards Blockchain implementation, and the profits that could be generated are topics under development in the background (Alkahtani et al., 2021; Bendarag et al., 2022; Da Silveira et al., 2022; Georgescu et al., 2022).

Regarding the economic dimension, different digitalized models such as the Food Trading System with Consortium Blockchain (FTSCON), FarmMarketPlace, or KRanTi offer a reduction of information asymmetry, as well as allowing for knowledge of losses during logistics services and guaranteeing the necessary authentications for permissions, and above all, promoting traceability throughout the chain (Leduc et al., 2021; Mao et al., 2018; Patel et al., 2021). Additionally, there are opportunities for improvement in the field of negotiations between small agricultural producers and the market, as the application of Blockchain can provide information throughout the chain, ensuring a reliable method of communication in the Vietnamese market (Nguyen et al., 2022). Furthermore, the diversification of the application of Blockchain in agricultural credits (Landini, 2021; Tende et al., 2022), the addition of cryptocurrencies in agri-food chains (Lotfi et al., 2021), and the monetization of chain data (Tsolakis et al., 2022) continue to add to the literature within the applications of sustainable intelligent economic ecosystems.

Finally, in the environmental dimension, it is understood that agricultural and food systems are transitioning towards a revolutionary agriculture. One application for reducing food labels or tags is information and traceability based on Blockchain technology (Sodamin et al., 2022). Additionally, the enabling or adoption factors from different studies demonstrate how pricing, trust, compliance, interoperability, and traceability, visibility, immutability, and technical characteristics of Blockchain enable the chain to help the agri-food chain's processes remain sustainable (Anastasiadis et al., 2022; Y. Bai et al., 2021; Erol et al., 2022; Köhler & Pizzol, 2020; Munir et al., 2022; Saurabh & Dey, 2021; Yadav et al., 2021; F. Zhang & Song, 2022; Zkik et al., 2022). However, the prevention of food loss and waste has rarely been the primary adoption factor for Blockchain technology (Benyam et al., 2021).

Furthermore, in literature, there are various approaches to the use of Blockchain in the food chain, for example: smart city management at different levels of the food chain (Ullah et al., 2023), integration of IoT and Blockchain to reduce the energy consumption of the system (Awan et al., 2021), IoT and Blockchain-based solutions for chain communication (Tanrıverdi, 2021), proposals for Blockchain-based architecture models for Supply Chain (Alamsyah et al., 2022; Y. Bai et al., 2021; Ekawati et al., 2021; Ma & Zhang, 2022; Song et al., 2021). Under this perspective, conceptual and analytical approaches allow us to show that the application of Blockchain plays important roles not only as an input to ensure fair prices (Mangla et al., 2022) but also as a mediator to obtain sustainability and improve supplier trust (Luzzani *et al.*, 2021; Nayal *et al.*, 2021; Kumar, Srivastava and Singh, 2022; Rashid *et al.*, 2022; Yousefi and Mohamadpour Tosarkani, 2022). Similarly, for the generation of new knowledge, the addition of sensors combined with Artificial Intelligence (Jararweh et al., 2023)**.** .

Other topics identified in the literature, which contribute to the present research, for example: studies on Blockchain and carbon footprint and carbon measurement in sustainable chains considering mathematical models (Abbasi & Erdebilli, 2023; Barbosa, 2021), the application of neural networks for the implementation of Blockchain (Faasolo & Sumarliah, 2022), Blockchain and circular economy (Rusch et al., 2022), empirical case study of Blockchain application (J. Zhang et al., 2022), multi-chain models with Blockchain (Yu et al., 2021), and some other updated systematic reviews or conceptual frameworks that give a thorough rundown of the advantages, advantages, applications, and limitations of Blockchain implementation (Chandan et al., 2023; Dal Mas et al., 2023; Rusch et al., 2023).

Method

The research design was developed in 4 phases that allowed to organize the application of Systematic Review and Meta- Analyses (PRISMA). Figure 2 shows the research design.

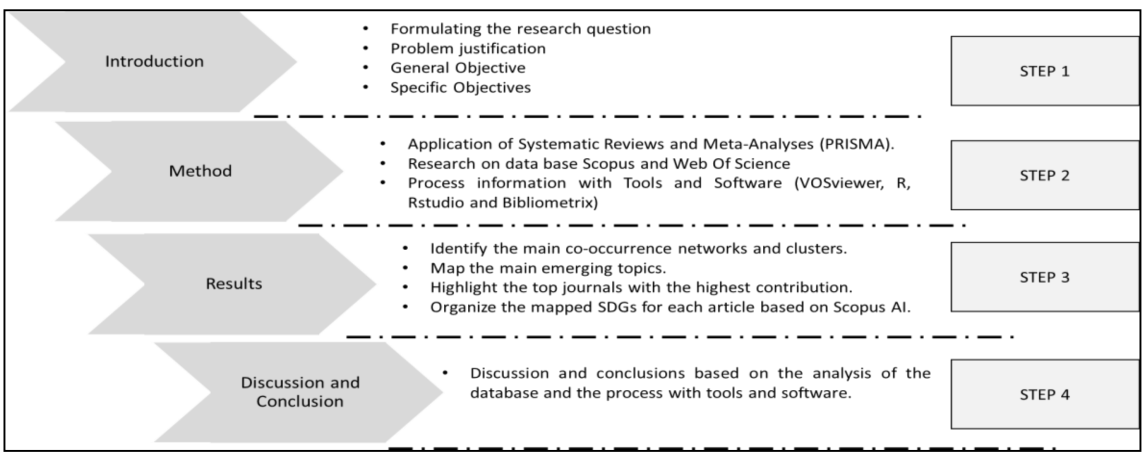

Figure 2. Research Design

The first step introduces four basic elements for the present study, which are the research question, proposed problem, the general objective, and the specific objectives.

The second step presents the methodology, based on PRISMA and databases such as Scopus and Web of Science. aims to achieve the specific objectives presented initially and is according to systematic literature review and bibliometric analyses following the Systematic Reviews and Meta-Analyses (PRISMA) model, which ensures replicability and transparency (Dabees et al., 2023; Morelli & Ignacio, 2021; Munir et al., 2022).

The third step presents the study results.

The fourth and final step includes the Discussion and Conclusion section, organized into findings and limitations, with the final section comprising future recommendations.

Development and results

The PRISMA procedure was applied in fourth stages: Identification, Screening, Eligibility and Including, as showing in Figure 3.

Identification: The keywords "Blockchain" and "Sustainable Development" and "Agri-food supply chain" or “Food Supply” were defined, which allowed for a high number of potential studies to be analyzed. Therefore, the articles obtained in the Web of Science database were 315 articles and in Scopus was 498 articles, respectively.

Screening: The Screening criteria were established as follows: only scientific articles published in scientific journals, articles published since the year 2000, in English, without duplicates, with a Digital Object Identifier (DOI), and finally, those not related to the topic of this research were excluded.

Eligibility: The Eligibility criteria were aligned with the studied topics shown in this research.

Including: Consequently, the result was 86 articles selected according to the inclusion criteria.

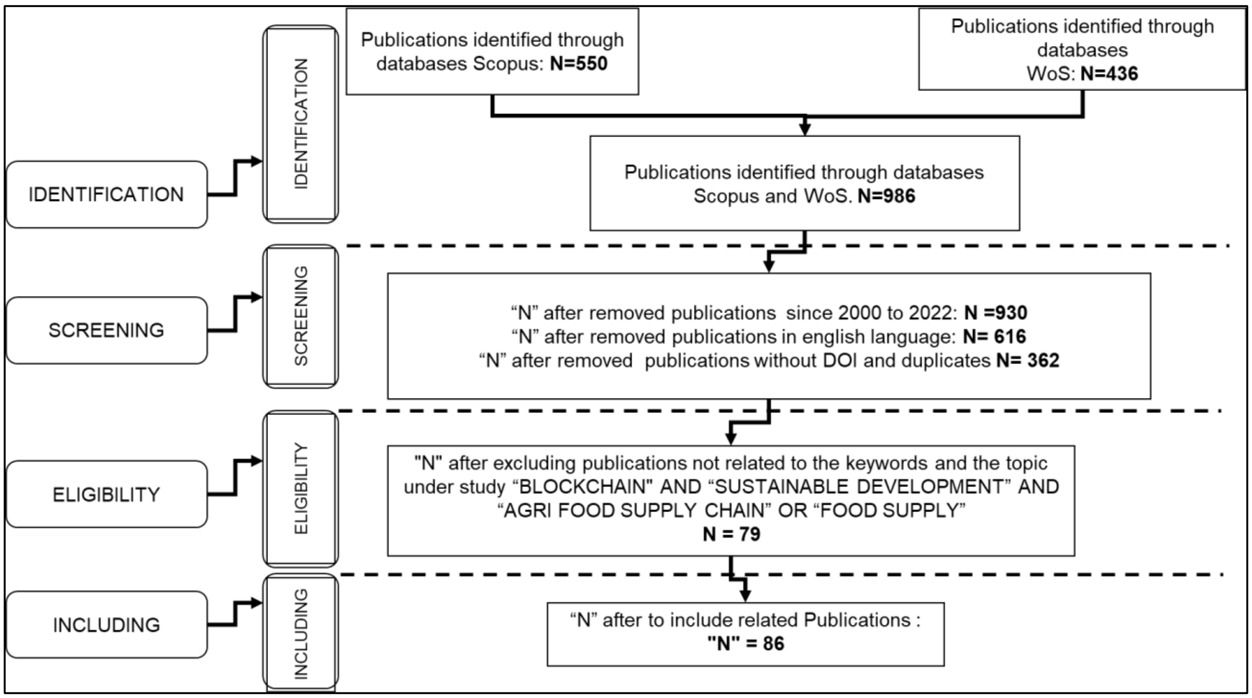

Figure 3. PRISMA flow.

In order to contribute to the research, the Rstudio software and Bibliometrix package, VOSViewer, and Thesaurus tool were used, which allowed this article to present different results which may respond to the research questions posed at the start of this piece. Figure 4 shows the performance of the database.

Completeness of bibliographic metadata

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
C1	Affiliation	0	0.00	Excellent
AU	Author	0	0.00	Excellent
CR	Cited References	0	0.00	Excellent
DI	DOI	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
RP	Corresponding Author	4	5.06	Good
DE	Keywords	6	7.59	Good

Figure 4. Metadata performance.

According to Figure 4, the data utilization by columns is an indicator that guarantees the suitability of the processed data. The data organized in the Metadata header refers to the order of the database, and each of them has a description on the right side. An important observation can be made in the last 2 rows (Corresponding author and Keywords), which present missing data, but they can still be used since the software rates their usage as "good".

Subsequently, the growth of literature on the studied topics allowed mapping the co-occurrence networks that were analyzed with VOSviewer and Thesaurus. Thus, we present Figure 5, which shows the co-occurrence networks and the identified clusters.

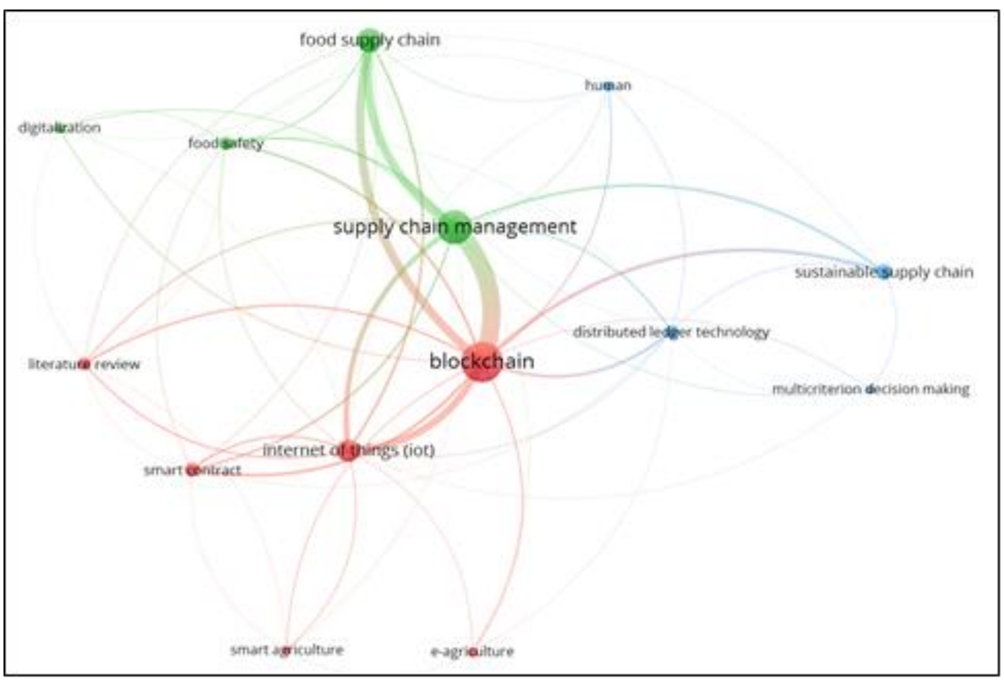

Figure 5. Co-occurrence Network

The co-occurrence networks demonstrate a convergence of the studied topics. Additionally, the existence of three clusters, Red, Blue, and Green, can be observed. Thus, the identified network is linked to Blockchain, Supply Chain Management, traceability, e-agriculture, sustainable development, and food security and safety.

Regarding the authors and journals with the highest contribution, Table 1 shows the top 21 authors with the highest citation levels within the literature linked to their respective journals.

The authors with the highest citation levels within the studied topic, including relevant research from the current year, 2023, may not have a high citation level due to recent publications, but contribute to new approaches within the literature. The Author column displays the identified authors belonging to the ranking. The Source column shows the international journals where the publications were made. The DOI column indicates the Digital Object Identifier, which allows for easy access to the articles. Finally, the last column shows the total number of citations per article and author. Furthermore, many authors have focused their research on different categories and subcategories, presenting conceptual models, frameworks, mathematical models, interviews, expert opinions, and other case studies or analyses. In summary, the entire list presented with the respective citation level may be used for consulting papers with the highest contribution.

Table 1. The most important contribution for author and resource.

Author	Source	DOI	Ano	Total Citations
Kamble et al.	International Journal of Information Management	10.1016/j.ijinfomgt.2019.05.023	2020	262
Klerkx et al.	Global Food Security	10.1016/j.gfs.2019.100347	2020	144
Saurabh et al.	Journal of Cleaner Production	10.1016/j.jclepro.2020.124731	2021	88
Köhler et al.	Journal of Cleaner Production	10.1016/j.jclepro.2020.122193	2020	78
Mao et al.	Sustainability (Switzerland)	10.3390/su10093149	2018	55
Öztürk et al.	Soft Computing	10.1007/s00500-020-04831-w	2020	30
Barbosa, M.	Global Food Security	10.1016/j.gfs.2021.100517	2021	23
Davies et al.	Frontiers in Sustainable Food Systems	10.3389/fsufs.2018.00084	2018	18
Friedman et al.	Technological Forecasting and Social Change	10.1016/j.techfore.2021.121403	2022	15
Benyam et al.	Journal of Cleaner Production	10.1016/j.jclepro.2021.129099	2021	15
Alkahtani et al.	Sustainability (Switzerland)	10.3390/su13020816	2021	15
Leduc et al.	Journal of Cleaner Production	10.1016/j.jclepro.2021.127055	2021	13
Mercuri et al.	Sustainability (Switzerland)	10.3390/su13105619	2021	13
Quayson et al.	IEEE Transactions on Engineering Management	10.1109/TEM.2020.2996003	2021	12
Dal Mas et al.	Technological Forecasting and Social Change	10.1016/j.techfore.2022.122155	2023	6
Chandan et al.	Sustainability (Switzerland)	10.3390/su15032109	2023	4
Kumar et al.	Journal of Cleaner Production	10.1016/j.jclepro.2023.136894	2023	1
Tyagi et al.	Humanities and Social Sciences Communications	10.1057/s41599-023-01658-2	2023	0
Ullah et al.	Sustainable Cities and Society	10.1016/j.scs.2023.104697	2023	0
Jararweh et al.	Computers and Electrical Engineering	10.1016/j.compeleceng.2023.108	2023	0
Talpur et al.	International Journal of Interactive Mobile Technologies	10.3991/ijim.v17i08.39467	2023	0

Table 2 displays the analysis of the identified research, organized into 4 categories: Conceptual, Empirical, Modelling, and Technical (Chandan et al., 2023)**.** The Conceptual category comprises general descriptions, literature reviews, and theories. The Empirical category includes case studies, hypothetical tests, expert interviews, and expert seminars. The Modelling category corresponds to mathematical modelling, simulation modelling, and multicriteria decision-making. Lastly, the Technical category is based on frameworks or system models.

Table 2. Research Categories

Authors	**Research Categories**			
	Conceptual	**Empirical**	**Modelling**	**Technical**
(Kamble et al., 2020)	*		*	
(Mistry et al., 2020)	*			
(Dutta et al., 2020)	*			
(Salah et al., 2019b)	*	*		*
(Klerkx & Rose, 2020)	*			
(Antonucci et al., 2019)	*			
(Wamba & Queiroz, 2020)	*			
(Saurabh & Dey, 2021)	*			

Authors	Research Categories			
	Conceptual	Empirical	Modelling	Technical
(Shahid et al., 2020)	*			*
(Torky & Hassanein, 2020)	*	*		
(Köhler & Pizzol, 2020)	*	*		
(Khan et al., 2020)	*	*	*	*
(Hang et al., 2020)	*	*		*
(Vangala et al., 2021)	*			
(Mao et al., 2018)	*	*	*	*
(Rana et al., 2021)	*			
(Lin et al., 2020)	*			
(Niknejad et al., 2021)	*			
(Pranto et al., 2021)	*	*		*
(Pincheira et al., 2021)	*	*		*
(Öztürk & Yildizbaşi, 2020)	*		*	
(Friedman & Ormiston, 2022)	*	*		
(Yousefi & Mohamadpour Tosarkani, 2022)	*		*	
(Benyam et al., 2021)	*			
(Barbosa, 2021)	*			
(Alfandi et al., 2021)	*	*		
(Leduc et al., 2021)	*	*	*	*
(Lotfi et al., 2021)	*		*	
(Quayson et al., 2021)	*			
(Alkahtani et al., 2021)	*	*	*	*
(Bierbaum et al., 2020)	*			
(Dey & Shekhawat, 2021)	*			
(Awan et al., 2021)	*	*	*	*
(Y. Bai et al., 2021)	*	*	*	
(Davies & Garrett, 2018)	*			
(Rejeb et al., 2022)	*			
(Erol et al., 2022)	*	*	*	*
(Nayal et al., 2021)	*			
(Yadav et al., 2022)	*	*	*	
(Patel et al., 2021)	*	*		*
(dos Santos et al., 2019)	*	*		*
(Mercuri et al., 2021)	*	*		*
(Mangla et al., 2022)	*		*	
(Zhu et al., 2022)	*			
(Song et al., 2021)	*	*		*
(Rusch et al., 2023)	*			
(C. Bai et al., 2022)	*		*	*

Authors	Research Categories			
	Conceptual	Empirical	Modelling	Technical
(Faasolo & Sumarliah, 2022)	*			
(Anastasiadis et al., 2022)	*	*		
(Scuderi et al., 2022)	*		*	
(Song et al., 2022)	*	*		
(Bager et al., 2022)	*	*		*
(Mirabelli & Solina, 2021)	*			
(Sahoo et al., 2022)	*			
(Kazancoglu et al., 2023)	*		*	
(Kumar et al., 2022)	*	*		
(Zkik et al., 2022)	*		*	
(Tsolakis et al., 2022)	*	*		*
(Yu et al., 2021)	*	*		*
(Zhang et al., 2022)	*		*	
(Andersson et al., 2022a)	*	*		
(Munir et al., 2022)	*			
(Luzzani et al., 2021)	*	*	*	*
(Zhang & Song, 2022)	*		*	
(Tende et al., 2022)	*	*		*
(Wunsche et al., 2022)	*			
(Alamsyah et al., 2022)	*	*	*	*
(Oguntegbe et al., 2021)	*	*		
(Fernandez-Vazquez et al., 2022)	*		*	
(Georgescu et al., 2022)	*		*	
(Ekawati et al., 2021)	*		*	*
(Rashid et al., 2022)	*	*		
(Sodamin et al., 2022)	*			
(Ma & Zhang, 2022)	*		*	
(Da Silveira et al., 2022)	*	*		
(Bendarag et al., 2022)	*			
(Nguyen et al., 2022)	*			*
(Landini, 2021)	*	*		*
(Tanrıverdi, 2021)	*			
(Dal Mas et al., 2023)	*			
(Chandan et al., 2023)	*			
(M. Kumar et al., 2023)	*		*	
(Tyagi, 2023)	*			*
(Ullah et al., 2023)	*			
(Jararweh et al., 2023)	*			
(Talpur et al., 2023)	*			

Table 2 also highlights the evaluation of the data collected based on the categories of Conceptual, Empirical, Modelling, and Technical. Consequently, it was identified that all the studies presented a solid theoretical foundation for the generation of different proposals, with the highest proportion of contribution being based on case studies and hypothetical tests. Additionally, of no less importance, was the existence of a mathematical application to measure the performance of Blockchain implementation in agri-food chains across different economic, environmental, and social approaches.

Table 3 displays the evaluation of the research determined by the specific approach they presented. As previously mentioned, the agri-food chain demonstrates applications in different focuses such as "Security, Safety and Quality," "Traceability, Tracking and Supervision," "Transparency and Decentralization," "Provenance," "Financial Performance," "Theoretical," and "Triple Bottom Line."

Table 3. Research Approach

Research Approach	Security, Safety and Quality	(Salah et al., 2019b); (Shahid et al., 2020); (Khan et al., 2020); (Hang et al., 2020); (Mao et al., 2018); (Pranto et al., 2021); (Alfandi et al., 2021); (Leduc et al., 2021); (Alkahtani et al., 2021); (Awan et al., 2021); (Erol et al., 2022); (Patel et al., 2021); (dos Santos et al., 2019); (Song et al., 2021); (Bager et al., 2022); (Yu et al., 2021); (Luzzani et al., 2021); (Zhang & Song, 2022); (Tende et al., 2022); (Alamsyah et al., 2022); (Ekawati et al., 2021); (Rashid et al., 2022); (Landini, 2021).
	Traceability, Tracking and Supervision	(Salah et al., 2019b); (Shahid et al., 2020); (Khan et al., 2020); (Hang et al., 2020); (Mao et al., 2018); (Pranto et al., 2021); (Pincheira et al., 2021); (Leduc et al., 2021); (Lotfi et al., 2021); (Alkahtani et al., 2021); (Awan et al., 2021); (Y. Bai et al., 2021); (Erol et al., 2022); (Patel et al., 2021); (dos Santos et al., 2019); (Song et al., 2021); (Anastasiadis et al., 2022); (Bager et al., 2022); (Kazancoglu et al., 2023); (Yu et al., 2021); (Luzzani et al., 2021); (Zhang & Song, 2022); (Tende et al., 2022); (Alamsyah et al., 2022); (Ekawati et al., 2021); (Rashid et al., 2022); (Ma & Zhang, 2022); (Nguyen et al., 2022).
	Transparency and Decentralization	(Salah et al., 2019b); (Shahid et al., 2020); (Khan et al., 2020); (Hang et al., 2020); (Mao et al., 2018); (Pranto et al., 2021); (Pincheira et al., 2021); (Alfandi et al., 2021); (Leduc et al., 2021); (Alkahtani et al., 2021); (Awan et al., 2021); (Y. Bai et al., 2021); (Erol et al., 2022); (Patel et al., 2021); (dos Santos et al., 2019); (Song et al., 2021); (C. Bai et al., 2022); (Anastasiadis et al., 2022); (Bager et al., 2022); (Kazancoglu et al., 2023); (Yu et al., 2021); (Luzzani et al., 2021); (Tende et al., 2022); (Alamsyah et al., 2022); (Ekawati et al., 2021); (Rashid et al., 2022); (Landini, 2021).
	Provenance	(Salah et al., 2019b); (Shahid et al., 2020); (Khan et al., 2020); (Hang et al., 2020); (Pranto et al., 2021); (Pincheira et al., 2021); (Leduc et al., 2021); (Awan et al., 2021); (Patel et al., 2021); (dos Santos et al., 2019); (Song et al., 2021); (Yu et al., 2021); (Luzzani et al., 2021); (Tende et al., 2022); (Alamsyah et al., 2022); (Ekawati et al., 2021); (Rashid et al., 2022).
	Finance Performance	(Salah et al., 2019b); (Shahid et al., 2020); (Mao et al., 2018); (Pranto et al., 2021); (Leduc et al., 2021); (Lotfi et al., 2021); (Alkahtani et al., 2021); (Patel et al., 2021); (dos Santos et al., 2019); (Song et al., 2021); (Bager et al., 2022); (Yu et al., 2021); (Luzzani et al., 2021); (Tende et al., 2022); (Alamsyah et al., 2022); (Ekawati et al., 2021); (Rashid et al., 2022); (Ma & Zhang, 2022); (Landini, 2021).
	Theoretical	(Kamble et al., 2020); (Mistry et al., 2020); (Dutta et al., 2020); (Salah et al., 2019b); (Klerkx & Rose, 2020); (Antonucci et al., 2019); (Wamba & Queiroz, 2020); (Saurabh & Dey, 2021); (Shahid et al., 2020); (Torky & Hassanein, 2020); (Köhler & Pizzol, 2020); (Khan et al., 2020); (Hang et al., 2020); (Vangala et al., 2021); (Mao et al., 2018); (Rana et al., 2021); (Lin et al., 2020); (Niknejad et al., 2021); (Pranto et al., 2021); (Pincheira et al., 2021); (Öztürk & Yildizbaşi, 2020); (Friedman & Ormiston, 2022); (Yousefi & Mohamadpour Tosarkani, 2022); (Benyam et al., 2021); (Barbosa, 2021); (Leduc et al., 2021); (Lotfi et al., 2021); (Quayson et al., 2021); (Alkahtani et al., 2021); (Dey & Shekhawat, 2021); (Awan et al., 2021); (Rejeb et al., 2022); (Erol et al., 2022); (Nayal et al., 2021); (Yadav et al., 2022); (Patel et al., 2021); (dos Santos et al., 2019); (Mercuri et al., 2021); (Mangla et al., 2022); (Zhu et al., 2022); (Song et al., 2021); (Rusch et al., 2023); (Faasolo & Sumarliah, 2022); (Scuderi et al., 2022); (Song et al., 2022); (Bager et al., 2022); (Mirabelli & Solina, 2021); (Sahoo et al., 2022); (Kazancoglu et al., 2023); (Kumar et al., 2022); (Zkik et al., 2022); (Tsolakis et al., 2022); (Yu et al., 2021); (Zhang et al., 2022); (Munir et al., 2022); (Luzzani et al., 2021); (Zhang & Song, 2022); (Zhang &

		Song, 2022); (Tende et al., 2022); (Wunsche et al., 2022); (Alamsyah et al., 2022); (Oguntegbe et al., 2021); (Fernandez-Vazquez et al., 2022); (Georgescu et al., 2022); (Ekawati et al., 2021); (Rashid et al., 2022); (Sodamin et al., 2022); (DA SILVEIRA et al., 2022); (Bendarag et al., 2022); (Nguyen et al., 2022); (Tanrıverdi, 2021); (Chandan et al., 2023); (M. Kumar et al., 2023); (Tyagi, 2023); (Ullah et al., 2023); (Jararweh et al., 2023); (Talpur et al., 2023).
	Triple Button Line	(Kamble et al., 2020); (Mistry et al., 2020); (Dutta et al., 2020); (Salah et al., 2019b); (Klerkx & Rose, 2020); (Shahid et al., 2020); (Hang et al., 2020); (Mao et al., 2018); (Lin et al., 2020); (Niknejad et al., 2021); (Pincheira et al., 2021); (Öztürk & Yildizbaşi, 2020); (Friedman & Ormiston, 2022); (Benyam et al., 2021); (Barbosa, 2021); (Leduc et al., 2021); (Bierbaum et al., 2020); (Dey & Shekhawat, 2021); (Awan et al., 2021); (Y. Bai et al., 2021); (Davies & Garrett, 2018); (Erol et al., 2022); (Nayal et al., 2021); (Patel et al., 2021); (dos Santos et al., 2019); (Mercuri et al., 2021); (Mangla et al., 2022); (Faasolo & Sumarliah, 2022); (Bager et al., 2022); (Mirabelli & Solina, 2021); (Kumar et al., 2022); (Andersson et al., 2022a); (Munir et al., 2022); (Luzzani et al., 2021); (Tende et al., 2022); (Georgescu et al., 2022); (DA SILVEIRA et al., 2022); (Bendarag et al., 2022); (Nguyen et al., 2022); (Landini, 2021); (Dal Mas et al., 2023); (M. Kumar et al., 2023); (Jararweh et al., 2023).

Table 3 reinforces the idea that there is a larger quantity of theoretical studies among the identified research. Some of these studies are linked to the triple bottom line, while others are proposals from startups and case studies that generate discussion around the tools used. Thus, it can be seen that in the near future there is an opening for research on topics related to sustainable development, agri-food chains, and the application of Blockchain based on tangible returns.

The thematic axes derived from the articles and the analyses conducted earlier. The thematic axes are organized into four quadrants, as show in Figure 6.

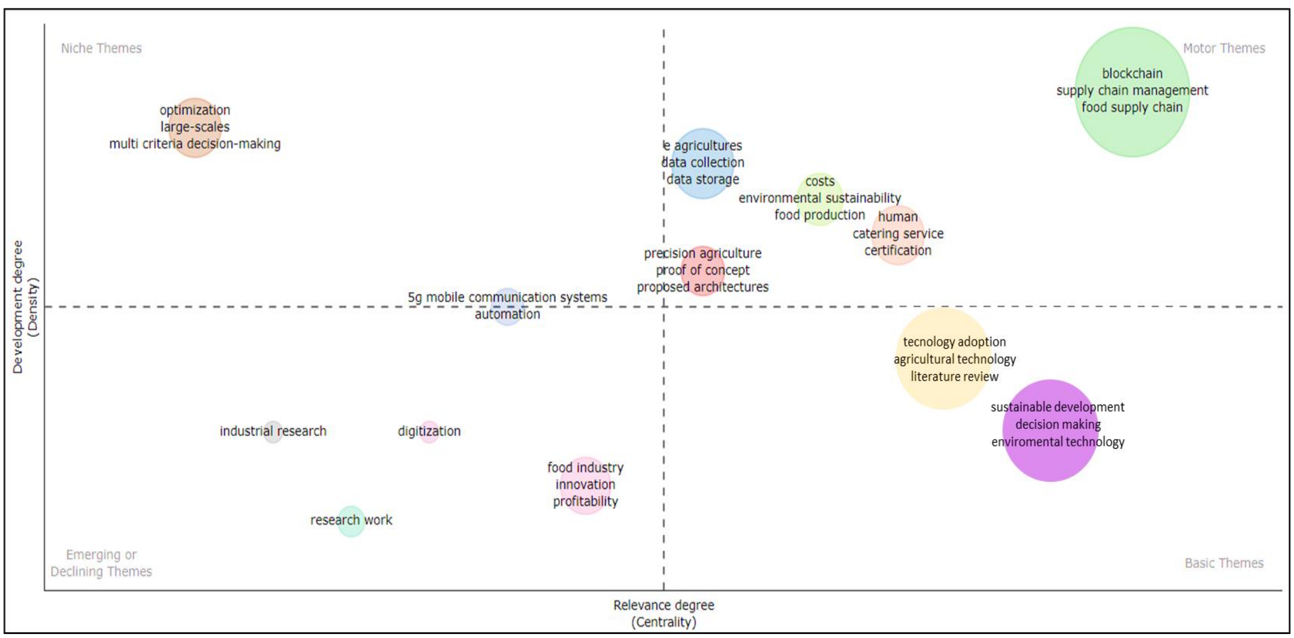

Figure 6. Thematic axes.

The identified thematic axes within the literature can be observed. In this sense, Basic Themes show the basic topics that are commonly studied in the literature, Motor Themes present the topics with relevance at the time of the review, Niche Themes show specific study topics, and finally Emerging or Declining Themes show axes that are growing or declining. Notice that the studied topic in this research is located within the Motor Themes and Basic Themes quadrant.

On the other hand, based on the results of the identification of different research in the studied literature and predictive machine learning of the Scopus database, Figure 7 presents the different SDGs linked to the research, and as part of the analysis, they were allocated in different sustainability dimensions based on the Stockholm Resilience Centre (Stockholm Resilience Centre's, 2017).

	Sustainable Development Goals SDGs	(Kamble et al., 2020)	(Mistry et al., 2020)	(Dutta et al., 2020)	(Salah et al., 2019b)	(Klerkx & Rose, 2020)	(Antonucci et al., 2019)	(Wamba & Queiroz, 2020)	(Saurabh & Dey, 2021)	(Shahid et al., 2020)	(Torky & Hassanein, 2020)	(Köhler & Pizzol, 2020)	(Khan et al., 2020)	(Hang et al., 2020)	(Vangala et al., 2021)	(Mao et al., 2018)	(Rana et al., 2021)	(Lin et al., 2020)	(Niknejad et al., 2021)	(Pranto et al., 2021)	(Pincheira et al., 2021)	(Öztürk & Yildizbaşi, 2020)	(Friedman & Ormiston, 2022)	(Yousefi et al., 2022)	(Benyam et al., 2021)	(Barbosa, 2021)	(Chandan et al., 2023)	(Dal Mas et al., 2023)	(Kumar et al., 2023)	(Tyagi et al., 2023)	(Ullah et al., 2023)	(Jraweh et al., 2023)	(Talpur et al., 2023)
ECONOMIC	8					x																			x					x		x	x
	9		x			x							x		x				x					x	x	x		x	x			x	x
	12	x				x			x						x		x			x			x	x	x			x	x	x	x		x
	10																								x								
SOCIAL	1																																
	2	x				x	x		x		x			x		x	x	x		x					x	x		x	x			x	
	3																																
	4																																x
	5																																
	7																			x											x		
	11		x																												x		
	16																																
ENVIROMENT	6																			x													
	13																									x						x	
	14																																
	15																																
	17	x				x										x						x			x				x	x			x

Figure 7. SDGs and papers based on triple button of development sustainable.

This research identified 32 articles as the main ones, each with their respective SDGs. In this sense, six researches that were not identified with the SDGs were excluded in the overall assessment, and it was observed that there is a greater concentration of research linked to SDGs 12, 9, and 2, concentrating almost 60% of the data frequency. The dimensions with the highest number of studies are the economic and social dimensions, highlighting an opportunity to link research with the third environmental dimension.

Finally, the results were presented and organized, aiming to achieve the specific objectives presented in the introduction of this research. As detailed, the results are entirely based on the literature consulted in the last semester of 2022.

Managerial Implications and practical insights

With the development of writing, numerous writers' diverse Blockchain applications in the agricultural and food industry offer a comprehensive view. Therefore, a first reflection on Blockchain is that it should not be considered a panacea, but rather a catalyst for unexplored improvements (Klerkx & Rose, 2020). Furthermore, it reinforces the idea that Blockchain technology contributes to the development of new sustainable business models(Dal Mas et al., 2023).

It is also worth noting that initially the assertion that the convergence between the terms Blockchain, Agri-food Supply Chains, and Sustainable Development was a little-studied idea, but now, with the presentation of different analyses, it has been demonstrated that these terms are not opposed to each other. On the contrary, this convergence allows for contributions to and the development of sustainable practices.

It has been acknowledged the coexistence of new and interesting applications such as Artificial Intelligence, Deep Learning, and other technologies that enhance the performance of Blockchain implementation. In this regard, it can be affirmed that Blockchain is not an "independent" technology, but rather a technology that requires a set of technologies to improve performance and impact on sustainable chains (Köhler & Pizzol, 2020)**.**

Moving forward, the studied topic can be further explored due to the growing trend among authors and journals. Another observation derived from the analysis and results emphasizes that a significant proportion of the research is conceptual, with a smaller proportion combining mathematical models or test simulations. This indicates that there is still a gap to be addressed by researchers.

It is worth noting that the identified and addressed researches have focused on the various advantages and benefits that the application of Blockchain technology offers. In this case, there is a greater concentration of information and emphasis on theoretical concepts and conceptual models related to Blockchain, Sustainable Development, and Agri-food Chains. In contrast, there is little emphasis on demonstrating practical or simulated results in areas such as "Security, Safety and Quality," "Transparency and Decentralization," and "Provenance."

On the other hand, it is agreed upon that Blockchain technology needs an evaluation for its adoption, and whether its efficiency can surpass conventional technologies (Ullah et al., 2023)**.** Furthermore, it is known that the adoption of Blockchain technology is not easy, as it requires a phase of theoretical studies and a growing body of research that is gradually being disseminated. Additionally, many organizations have started with pilot projects to test certain outcomes, and if these outcomes add value, they share that value in the chain (Dal Mas et al., 2023; Friedman & Ormiston, 2022; Lim et al., 2021; Song et al., 2022), or determine whether the adoption is worthwhile (Tyagi, 2023)**.**

Furthermore, the literature review allowed us to know the thematic axes organized into four quadrants within which the present research is developed. In this sense, taking advantage of the organization of data and topics, the relevance of the study can be noted since topics such as environmental sustainability, Blockchain, Food Supply Chain, precision agriculture, and certification. However, topics such as digitalization or innovation are known in general dimensions.

Additionally, the identified articles related to the SDGs allowed for their allocation within the different dimensions of sustainability, in line with the proposal of the Stockholm Resilience. As a result, a greater concentration of research was observed within the economic and social dimensions, but the environmental dimension did not show similar results. This is a concern since SDGs 6, 13, 14, and 15 are focused on environmental preservation.

Conclusions, limitations and future works

Conclusions

Regarding the conclusions, the first consideration is that the convergence between the application of Blockchain technology in AgriFood Supply Chains and Sustainable Development was mapped and evidenced. Thus, it can be affirmed that the application of Blockchain in agri-food supply chains is related to sustainability. Moreover, it is confirmed that Blockchain may have limited effectiveness if applied independently and without the support of other technologies such as IOT, sensors, drones, machine learning, and others. Additionally, Blockchain is not a solution that can address all the current challenges of the chain. Instead, it should be considered as a path that relies on the managers and responsible individuals for its application in different scenarios.

The second consideration allowed for knowing the relevance of this study, not only due to the growing trend of publications related to the addressed study but also due to concerns associated with disruptions in global agri-food chains caused by COVID-19, the Ukraine War, food contamination, food waste, and others. Thus, the present proposal highlighted the significant contribution of Blockchain technology application in creating new management models, sustainable businesses, and improving processes throughout the chain.

Furthermore, it is worth noting that many authors have highlighted post-application benefits, considering "Security, Safety and Quality," "Traceability, Tracking and Supervision," "Transparency and Decentralization," "Provenance," and "Financial Performance" as the most important factors.

The third consideration emphasizes the added value that Blockchain technology can offer in certain applications. It was observed that larger companies demonstrated the addition of value in their operations through Blockchain implementation. However, applications in small and medium-sized enterprises were not identified in the present study, indicating the need for a prior evaluation of the opportunity cost for adopting Blockchain technology.

The fourth consideration highlights that the various applications of Blockchain are still in development, not in the initial stages nor in advanced stages, but in a relatively mature stage that allows for the integration of disruptive technologies and the acquisition of new knowledge and management approaches. This aligns with the findings presented within the studied and presented quadrants.

The fifth and final consideration allowed for linking the 86 research studies to their relationship with the SDGs within the dimensions of Economic, Social, and Environmental. It was observed that the economic and social dimensions were the most addressed, while the environmental dimension had the lowest frequency. Thus, it can be stated that the different studies are primarily focused on financial returns rather than environmental preservation, which is an issue that needs to be further studied and addressed.

Finally, the objectives of this article have been achieved, allowing for the presentation of various novelties related to the proposed research.

Limitations

Regarding the limitations of the present investigation that can be overcome by future approaches, the following are noted:

1. Reducing information bias.
2. Many research studies were disregarded due to not being in the English language and lacking a DOI.
3. There was extensive complexity and heterogeneity of data for analysis, which may reduce objectivity.

Future Works

Agri-food chains offer constant challenges and new opportunities as all chains are dynamic. In this regard, it is recommended that further research address the following topics:

1. Scaling up the implementation of smart contracts and Blockchain in different supply chain processes.
2. Ensuring security with tested mechanisms and tools in Blockchain networks.
3. Demonstrating and ensuring the efficiency of intelligent certifications for international physical distribution (FDI).
4. Highlighting the specific impacts of Blockchain technology adoption on the three dimensions of sustainability and proposing new application methods related to the environmental dimension (SDGs 6, 13, 14, and 15).
5. Proposing a theoretical framework or framework on the opportunity cost presented by the adoption of Blockchain in relation to traditional technologies.

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