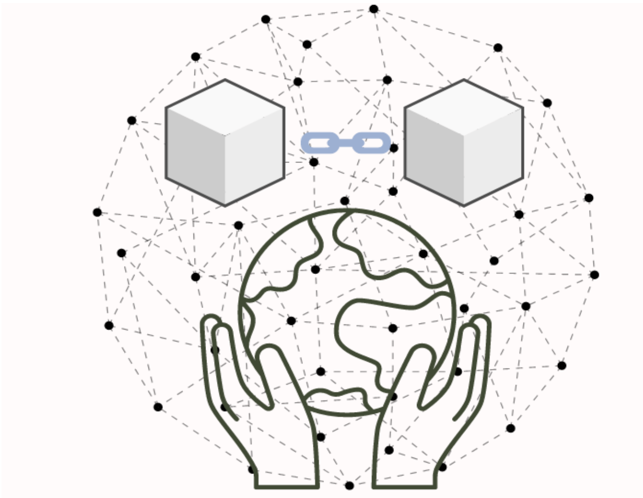

HOW CAN BLOCKCHAIN TECHNOLOGY IMPROVE SUSTAINABILITY IN THE AGRI-FOOD SUPPLY CHAIN FROM A GLOBAL PERSPECTIVE?

A Literature-Based Analysis

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Katarzyna Rudzka

Supervisor: Agnieszka Urszula Nowińska
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Abstract

The purpose of this research paper is to investigate what are the results of blockchain technology implementation in the agri-food supply chain when addressed to improve sustainability. This study discusses the influence of blockchain technology application in sustainability matters in the agri-food supply chain and agri-food production, bringing the aspect of food safety.

This study is literature based, meaning that the analysis part of the research is based on literature selection and the word data is a subject for the analysis, as no primary data was collected in this study.

This research demonstrates global problems related to food waste and low technical and economic resources in developing countries. Furthermore, the study identifies the barriers to blockchain technology implementation, which have a significant impact on the outcome of this research, stating that the majority of potential positive effects of blockchain technology implementation in the agri-food supply chain are not valid when facing the barriers to implementation of this technology in these settings.

The research also identifies food safety as the most promising aspect for a successful blockchain deployment to address sustainability matters and calls for action to policymakers and regulatory bodies to address global sustainability issues.

Keywords: blockchain technology, agri-food supply chain, agri-food sector, food safety, food traceability, sustainability, blockchain barriers

Abbreviations

BCT – Blockchain Technology
EC – European Commission
ECB – European Central Bank
EU – European Union
FAO – Food and Agriculture Organization of the United Nation
UN – United Nations
UNCC – United Nations Climate Change
UNEP – United Nations Environment Programme
RQ – Research Question
SC – Supply Chain

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1. Introduction

1.1. Research Context

The research context incorporates sustainability matters in agri-food supply chain (SC) and a possible use of blockchain technology for its improvement. It also discusses barriers to blockchain implementation from a global perspective and explains their consequences.

Nowadays, sustainability concerns, to a large extent, are dependent on sustainability of food supply chains and food safety in this context is intensively discussed. To attain food security sustainability matters need to be addressed (Kaur, 2019). The United Nations Environment Programme (UNEP) states that agriculture and food consumption are the major drivers of environmental sustainability (UNEP, 2010), and scholars argue that the agri-food sector negatively affects the environment and contributes to climate change (Wünsche & Fernqvist, 2022).

The focus of this research is on agri-food supply chain specifically, as this supply chain is complex and agri-food trade consists of many stakeholders requiring safe and high-quality food with detailed information about it (Antonucci, Figorilli, Costa, Pallottino, Raso, & Menesatti, 2019). A big problem in agricultural supply chains is that from one side there is a shortage of food, and from the other there is enormous food waste in containers worldwide (Sodamin, Vaněk, Ulman, & Šimek, 2022). About one-third of all food produced is lost or wasted globally (Wünsche & Fernqvist 2022) The issue is amplified by the reason that most agricultural products are perishable, hence the usage of inventory as a buffer for demand and transportation is limited (Sodamin et al., 2022). This matter has severe implications for firms' inefficiencies in the food chain and it is costly for society as the resources are wasted (Wünsche & Fernqvist 2022).

The focus being directed to agri-food supply chain particularly was made on the premise that agricultural supply chains are more difficult to manage as they deal with food safety, food quality, and limited shelf life and they need to attain stable networks and relations between their stakeholders (Sodamin et al., 2022). At the same time, they are negatively contributing to sustainability matters. The dimension of blockchain technology (BCT) is added based on scholars' articulations that a digital transformation is seen as a crucial element in addressing challenges in the agri-food system (Klerkx & Rose, 2020; Shepherd, Turner, Small, & Wheeler, 2020).

Agricultural firms are investing in modern, technologically advanced technologies in the agri-food supply chain to achieve food safety and reliability (Alkahtani et al., 2021) and BCT is one of such technologies (Bhat, Huang, Sofi, & Sultan, 2022). The application of blockchain technology in agriculture has been rapidly rising (Van Wassenaer, van Hilten, van Ingen, & van Asseldonk, 2021) and there is an increase in blockchain-based agricultural solutions (Juma, Shaalan, & Kamel 2019). The BCT is seen as the most transformative digital technology within the agriculture sector. This technology can stop food fraud, promote food safety, and affirm legitimacy of agricultural commodities (Bagwasi and Raja, 2020; Sodamin et al., 2022).

Currently, food products are manufactured through globally extended supply chains which include many actors (Pavlic Skender & Zaninovic, 2020), and the application of blockchain affects the governance of business activities on a global scale, and it is changing traditional business processes, (Hooper & Holtbrügge, 2020). Blockchain technology is seen as a contribution to sustainability and efficiency of global food production. (Wünsche & Fernqvist, 2022). Thus, the combination of food supply chain's effect on sustainability, agriculture's negative contribution to environmental issues and a rise of blockchain implementation in this sector creates an interesting starting point for investigation.

There is plenty of information on BCT's application for sustainability improvement in supply chains in general but in the context of agri-food supply chain specifically the amount of data is significantly smaller. Moreover, opposed to claims about BCT positive contribution to sustainability matters, there is plenty of contradicting information, referring to the negative effects of blockchain deployment or difficulties of its implementation for global distribution . Furthermore, there is not enough publications incorporating global dimension in a combination of these subjects. Thus, the identified research gap incorporates investigation whether BCT could achieve improvement of sustainability matters in agri-food supply chain in spite of barriers to BCT implementation from a global perspective.

Although the scope of the research refers to the agri-food supply chain, it is necessary to narrow this concept down, where several aspects need to be addressed in this matter separately. That serves comprehension of the research topic in the most effective way. Therefore, this study includes five elements of investigation to provide an understating of BCT effect on possible improvement of sustainability matters in the agri-food supply chain from a global perspective. These are: BCT for sustainability in agri-food supply chain; BCT for sustainability in agri-food sector; BCT for food safety in agri-food supply chain; barriers to BCT implementation,; and the global aspect as a connecting element of all.

1.2. Problem Formulation and Research Questions

Based on the above described research context, the problem formulation for investigation in this research was developed:

"How can blockchain technology improve sustainability in the agri-food supply chain from a global perspective?"

The objective of this study based on this problem formulation is to investigate what positive effect on sustainability in the agri-food supply chain would the implementation of BCT have in this setting while approaching this matter from a global perspective.

To perform a comprehensive analysis of this problem additional four research questions (RQs) were developed:

RQ1. How can blockchain technology improve sustainability in the agri-food supply chain?

The aim of this research question is to identify BCT effect on the agri-food supply chain at the bigger picture, discussing the nature of transactions between agri-food supply chain members and analyze a food product journey from farm to the end customer.

RQ2. How can blockchain technology improve food safety in the agri-food supply chain?

This research question provides detailed viewpoint on food safety as a significant part of sustainability issues in the agri-food supply chain and application of BCT for this purpose.

RQ3. How can blockchain technology improve sustainability in the agri-food sector?

This part of the research investigates effect of BCT on sustainability matters, specifically in agri-food sector, which is a part of agri-food supply chain. This research question is mostly concerned about how the application of BCT in farming and agri-food production contributes to overall sustainability of agri-food supply chain.

RQ4. What are the barriers to blockchain technology implementation in the agri-food supply chain and agri-food sector?

This research question is leading the analysis to the other side of investigation, being more of a critical approach to the problem formulation. It approaches the research from another standpoint, identifying weak points of BCT implementation in agricultural settings and, at the same time, evaluating what impact the identified barriers may have in relation to the problem formulation.

At this point, it is worth mentioning that the global aspect of this research's topic is not included in the research questions because there was no sufficient data to support debate on the aspects included in the problem formulation. However, the global dimension and its relevance to the problem formulation is explained in a part of literature review.

1.3. Project Outline

This study is structured as follows: The very next section describes the methodology applied while conducting this research and explains how the relevant literature was collected. Afterwards, the literature review presents gathered data and discuss the concepts needed to be explored for the purpose of this research. It reviews publications regarding blockchain, sustainability, agri-food supply chain/sector, food safety, barriers to blockchain implementation and it sums up with the outlook on these aspects from a global perspective. Based on the information provided in the literature review, the literature analysis is performed, and, consequently, conceptual framework presented. Followingly, the discussion about practical implications, limitations, and further research ideas takes place. The conclusion is the closing part of this study.

2. Methodology

The following section provides an explanation of research methodological positioning and outlines the methods used to collect the selected literature and describes their relevance in the context of this thesis

2.1. Methodological Approach

Methodological assumptions explain how the researcher creates perceptions related to the research topic. Scholars argue that no matter if a researcher is aware of it or not, the choice of the research question and presumed appropriacy of methods used in research are based on underlying prior assumptions and views of a researcher (Kuada, 2012).

Kuhn (1970) states that every research corresponds to a set of prevalent and commonly accepted views about the phenomenon being studied, related to the type of questions that are used to ask about the phenomenon. These common characteristics create a paradigm (Kuhn 1970, cited in Kuada, 2012). A paradigm is a concept that helps to summarize and understand such assumptions in a descriptive way (Kuada, 2012) as it represents a set of beliefs or worldviews of a researcher applied to research choices and preferences (Cibangu, 2010).

Most of the time, paradigms are hidden under the actions and reasoning of a researcher. That means that to attain a correct research design, a researcher needs to become aware of their underlying paradigms. Once a hidden paradigm is realized, proper methods and methodologies lead to appropriate research decisions (Cibangu, 2010).

A method is a particular means to investigate a research question through data collection and data analysis. A methodology is a set of methods used in research (Cibangu, 2010). It is the strategy, design, and process that is underneath the choice and use of applied methods, which connects the preference and use of the methods with desired results (Gustomo, Herliana, Dhewanto, & Ghina, 2017).

2.1.1. Philosophy of Science

The philosophy of science is *"a field devoted to analyzing the character of scientific investigations"* (Bechtel, 2013, p.1). It *"analyses the entities of the social world from different aspects"* (Uddin & Hamiduzzaman, 2009, p. 654). Social research bounds philosophical analysis of methodological approaches which are based on ontological and epistemological assumptions (Uddin & Hamiduzzaman, 2009).

Ontology describes the researcher's perception of reality and their assumptions about reality (Kuada 2012; Cibangu 2010). It reflects the researcher's view on human nature. These perceptions constitute what the researcher identifies as truth and how to acquire knowledge about this truth. (Kuada, 2012)

Epistemology provides a philosophical base for choosing the kinds of knowledge applied in the research and how they can be ensured to be adequate. This philosophical approach helps to understand how we know what we know *(*Gustomo et al., 2017). Epistemology deals with a researcher's view on what constitutes and identify as acceptable knowledge in a study (Saunders, Lewis, & Thornhill, 2003).

2.1.2. Research Paradigm

The research paradigm, more specifically the research approach, I adopted in my research design is pragmatism**.**
Pragmatism is outcome-oriented and it puts emphasis on the research question (Shannon-Baker, 2016). Pragmatism supports mixed methods research in the social and behavioral sciences. Both qualitative and quantitative research methods can be used in the same research study. The key determinant of the epistemology and ontology a researcher adopts in the pragmatic approach is the research question, and it is perceived as a highly practical research philosophy (Tashakkori & Teddlie, 2002).

The pragmatic approach reflects that the values, beliefs, and behaviors of a researcher are inseparable from them. Pragmatist puts emphasis on the factors influencing what they choose to study and in which way they chose to do so (Morgan, 2007).

Pragmatism connects induction with deduction, creating abduction; it also connects subjectivity with the objectivity of a research process, creating intersubjectivity; and it combines context and generality into the concept of transferability (Morgan, 2007; Tran, 2017).

The pragmatic approach frees the researcher from the need to choose between contexts from two other sides of the spectrum. This approach enables a researcher to take obtained knowledge from a specific kind of method in one setting and apply it in other circumstances, involving a process of moving back and forth between particular outcomes and their more widespread implications (Morgan, 2007).

2.2. Research Methods

This research is a literature-based qualitative analysis. From the epistemological perspective, my relationship to the research process is based on intersubjectivity. Morgan (2007) argues that from the pragmatic point of view, it is not likely to be either completely subjective or completely objective.

I decided to choose multiple perspectives to answer the research question. With the use of four research questions, I attempted to answer the problem formulation most effectively, investigating four different approaches to the problem, and trying to understand various implications from different approaches to the topic. With the use of a pragmatic approach to my research, I was able to move back and forth between these distinct settings in relation to the identified problem to find the best solution.

As a researcher who applied a pragmatist approach, I considered the research question to be the most important guideline on how to collect the data. I incorporated a pragmatic view on the research study by following the statement "*Study what interests and is of value to you, study it in the different ways that you deem appropriate, and utilize the results in ways that can bring positive consequences within your value system"* (Tashakkori, Teddlie, & Teddlie 1998, p. 30).

To gain the desired knowledge in my study, I assumed that the social world can be observed from the outside, and I focused on collecting secondary data through qualitative research and no primary data was used. Gathered qualitative data was derived from words' meanings and they
were the object of my analysis. The results are classified into non-standardized data and the analysis is done with the use of conceptualization.

2.2.1. Data Collection

In this section, data collection methods used in this research will be presented. This research is literature-based, where secondary qualitative data is the object to the analysis of this study. Thus, the aim of this section is to provide specific explanation of the process of gathering data for this research. The process of data collection is presented in four phases.

To collect data I performed a systematic literature review.

Phase 1.

1.1. In my preliminary research the keywords were: blockchain, non-fungible tokens (NFTs), and International Business, however the concept of NFTs in the IB settings was too novel.

1.2. Another attempt was dedicated to the application of blockchain in the context of international trade. Having thoughtfully read publications to formulate my research questions, I dropped this idea as it was concerned with too many technicalities and I was not able to identify a research gap.

1.3. Having read many publications on blockchain technology I stumbled upon plenty of remarks mentioning the deployment of this technology for sustainability matters. Therefore, I decided to investigate possible ways of exploring this topic. I aimed to find a research gap, yet have enough data to work with. The key aspects for further investigation of the research topic were: blockchain, sustainability, international, and global.

Phase 2.

2.1. In the next stage I used "VOSviewer" (is *"a software tool for constructing and visualizing bibliometric networks*" (VOSviewer, 2023, p.1), whereby analyzing word clusters I could assess probable keywords for identifying desired research gap. (Some screenshots from this process can be found in the appendix).

2.2. Then, I was inserting these keywords in Scopus (abstract and citation database) to evaluate the number of corresponding publications.

2.3. Consequently, I narrowed down the aspects for further investigation: food sustainable supply chain management; sustainable food security system; smart contracts; blockchain-based food supply chain; sustainable supply chain management; cross border supply chain; digital supply chain; global supply networks; international supply chain management; global supply chain management.

2.4. With the process of trial and error by using the above-mentioned tools, and reviewing publications from the Scopus database, I was trying to find a research gap.

Phase 3.

The table below aims to illustrate how the number of publications were changing depending on the keywords of my investigation.

Keywords	Number of Publications in Scopus database
blockchain, sustainab*, supply chain	620
blockchain, international trade	279
blockchain, sustainab*, supply chain, global	114
blockchain, agri*, sustainab*, smart contract	34
blockchain, agri*, sustainab*, global food supply chain	21
blockchain, supply chain, food, international, sustainab*	13
blockchain, food, global value chain, sustainab*	9
blockchain, agri*, sustainab*, global food supply chain, smart contract	1

Table 1

3.1. Eventually, keywords that led me to formulate my problem formulation were: blockchain, agri*, sustainab*, global food supply chain

Phase 4.

Having identified problem formulation: *How can blockchain technology improve sustainability in the agri-food supply chain from a global perspective?* I pursued a pragmatic research paradigm, where I used an abductive research strategy.

To answer my problem formulation I designed four research questions. The pragmatic approach enabled me to seek helpful points of connection between different types of data, and as advised by Tran (2017), it helped me find a bridge between these different points of data and focus on what is the most meaningful from all of them in relation to my research.

- The databases I used for this purpose: Aalborg University Library, Scopus, and Google Scholar.
- The majority of sources used for data collection: Scientific and Academic Journals, Reports and Books.
- Number of publications thoughtfully reviewed and documented: 356
- Total number of publications presented in the ultimate literature review: 132

(The type of sources used for the final version of literature review can be found in Appendix A.)

3. Literature Review

This section presents selected literature to introduce the key concepts of this research and provides an extensive explanation of each of the topics that need to be addressed with the aim to answer the research questions of this study. This research is literature-based, meaning that literature presented in the following chapter is the only source of data that will be later used for the analysis part.

3.1. Blockchain

In the first section of the literature review, the concept of Blockchain Technology will be introduced. It is a comprehensive topic with many specific technological terms, therefore the focus will be on these aspects of blockchain that are most important to understand in relation to this research study.

3.1.1. Definition of Blockchain

The concept of blockchain was popularized by Satoshi Nakamoto (presumed to be a pseudonym), whose white paper on Bitcoin from 2008 was frequently cited and popularized. Nakamoto described the new peer-to-peer electronic payment system as *"based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party"* (Nakamoto, 2008, p.1).

Originally, blockchain was closely related to the digital currency – "Bitcoin". With the use of blockchain, every coin owner could transfer currency directly to every party connected to the same network, not including a financial institution to mediate such transactions (Nakamoto, 2008). In his paper about blockchain, Nakomoto described an electronic payment system allowing any two willing parties to make transactions without a need for a trusted third party. Such a system is based on cryptographic proof instead of trust, based on a peer-to-peer distributed timestamp server, which provides computational proof of the transactions and their chronological order. Nakomoto claimed that this system - blockchain technology would protect sellers from fraud, at the same time protecting buyers (Nakomoto, 2008).

The term, blockchain, consists of “block” and “chain”. The “block” refers to transactional records, which are transferred from one to another. The records are linked together by the “chain”, with a hash function (Okazaki, 2018). The transactions are grouped into blocks which are then linked together and timestamped in a chain (Hooper & Holtbrügge, 2020).

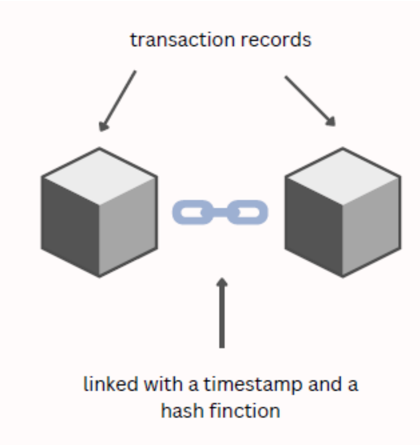

Figure 1

Blockchain. (Source: own creation, based on Hooper & Holtbrügge, 2020; Okazaki, 2018)

Even though the concept of blockchain was frequently related to the cryptocurrency, as a technology used for running its transactions, the BCT itself is not related to Bitcoin solely. It can be applied anywhere as a digital, trusted, and decentralized ledger and it is leveraged by a variety of businesses in different industries as a tool of distributed consensus (Hooper & Holtbrügge, 2020*).*

Blockchain is the most common type of distributed ledger technology, which is *“a set of tools for recording data, such as asset holdings or financial transactions, allowing a network of computers to verify and store updates without a single central management system”* (European Central Bank [ECB], 2017a, p.2). Nowadays, when an exchange of ownership or financial assets occurs, it is done via centralized systems, often run by central banks. After a transaction has taken place in the centralized system, the track of such transactions is stored in a local database. However, a distributed ledger is *“a database of transactions spread across a network of many computers, rather than stored in a central location”* (ECB, 2017b, p.1).

Most of the time, all participants of the network can read the information, and add to it (depending on their permissions). In a blockchain, transactions are grouped together and form blocks that are attached to each other in chronological order, thus forming a chain, that is secured with highly complex mathematical algorithms to guarantee the security and integrity of the data (ECB, 2017b).

Swan refers to the blockchain as a big spreadsheet where all assets are registered and a system for transacting all types of assets held by all the parties globally (Swan, 2015). Blockchain is another application layer to run on the stack of internet protocols that already exist, adding a whole new tier to the Internet to enable economic transactions, where any hard or soft asset may be transacted. BCT is used for recording, tracking, monitoring, and transacting all assets. It can also be used for any form of asset registry, such as inventory or exchange, including every area of finance, and economics, as well as hard assets and intangible assets (Swan, 2015). With the use of BCT, all digital assets are not stored in a central place but are distributed across a global ledger using millions of computers with the highest level of cryptography (Tapscott & Kaplan, 2019). The implementation of BCT is influencing exploring innovations to existing concepts and terminology and is inspiring new ways of doing business among many industries (Swan, 2015).

BCT enables the use of smart contracts, digital signatures, and multi-signatures and it facilitates authentic measurement of the performance of critical transactions and operation processes (Toorajipour, Oghazi, Sohrabpour, Patel, & Mostaghel, 2022). The operations performed on a blockchain are based on cryptography, which is a technique of writing and solving codes for a secure transfer of messages (Hooper & Holtbrügge, 2020). Transactions done within a blockchain are stored in a permanent and almost inalterable way by the use of cryptographic means. All the participants within a blockchain, who have no particular trust in each other, can collaborate without a need to rely on a trusted third party and they can access and check the ledger at any time. Transactions added to the blockchain are time-stamped, can be easily traced, and cannot be simply altered. Therefore, the blockchain is referred to as a "trust machine" (Ganne, 2018). Belu defines blockchain as a global registry where each client who logs into the network receives a copy of updated and validated data (Belu, 2019).

3.1.2. How Blockchain Works

The first block of a blockchain is called the "genesis block" as it has no parent block. Every next block in the sequence is linked to the very previous block through a reference that is essentially a hash value of the previous parent block (Zheng, Xie, Dai, Chen, & Wang, 2018). A block is made of the block header and the block body.

The block header consists of

- block version - indicating which set of block validation rules to follow
- timestamp
- hash value pointing to the previous block
- nonce

- *“hash value of all the transactions in the block”* (Zheng et al., 2018, p. 355).

Hash values are unique, meaning that any change of a blockchain would instantly change the respective hash value, hence it prevents any fraud (Zheng et al., 2018). Blockchain validates the authentication of transactions based on an asymmetric cryptography mechanism (Zheng et al., 2018) meaning that each block contains the hash value of the previous block and a random number (nonce) for verifying the hash. This process ensures the integrity of the entire blockchain (Nofer, Gomber, Hinz, & Schiereck, 2017).

The block body consists of a transaction counter and transactions. The amount of transactions that one block can carry is related to the size of a block and each transaction (Zheng et al., 2018).

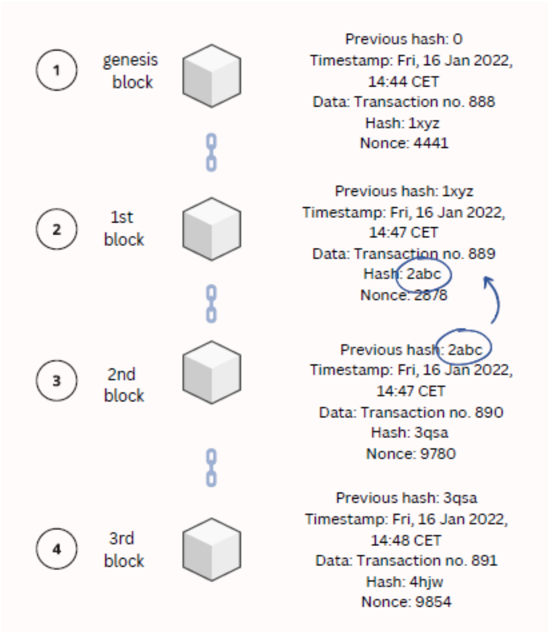

Figure 2

Simplified blockchain’s mechanism.
(Source: own creation, based on Ajao, Agajo, Adedokun, & Karngong, 2019, 2019; Zheng et al., 2018)

According to Hooper & Holtbrügge, blockchain is a decentralized network, which means that all of the information about the operations and transactions is not kept in one centralized place but is stored across the network. The operations and transactions on the blockchain network are performed and verified anonymously, and the records of transactions are publicly transmitted across the entire distributed network. (Hooper & Holtbrügge, 2020).

A mathematical puzzle called the proof-of-work, ensures that each block is only approved if the problem of the puzzle is solved and only if the chain accepts it as valid (Okazaki, 2018).). “Peer-to-peer verification” enables all the communication between peers to occur through a central node, where every node stores information and then passes it to all other nodes (Iansiti & Lakhani, 2017; Seebacher & Schüritz, 2017).

BCT enables safe and shared records of transactions, where this record is distributed to all participants in a network who don't know each other and who use their computers to validate these transactions. As a result, there is no need for a third party to intermediate in such events (Grewal-Carr & Marshall; Deloitte, 2016).

Transactions are performed based on a distributed trust, namely on the consensus of the other blockchain users (Fransicsco & Swanson, 2018). "*A consensus mechanism is the process in which a majority (or in some cases all) of network validators come to agreement on the state of a ledger"* (Swanson, 2015, p.4)

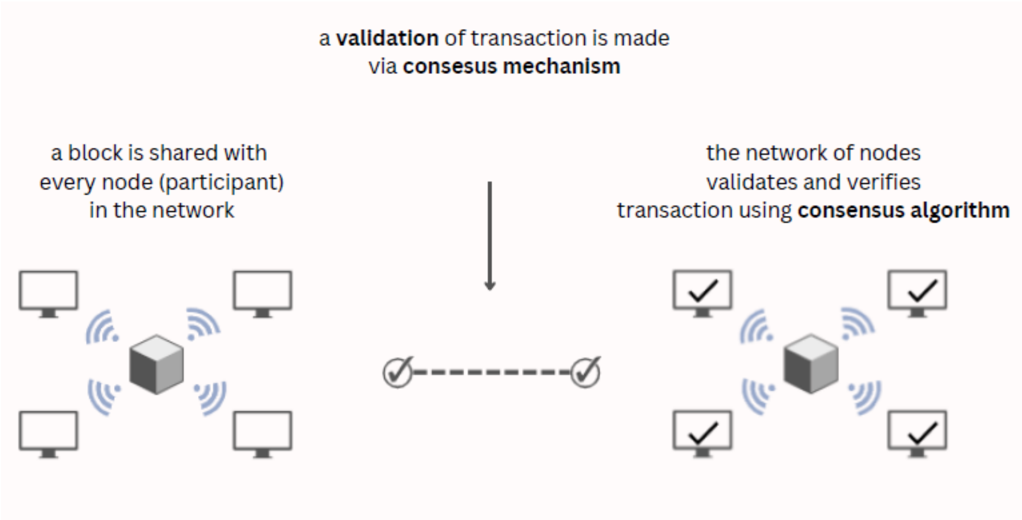

Figure 3

Consensus mechanism.
(Source: own creation, based on (Monrat, Olov, & Karl, 2019; Uddin & Hamiduzzaman, 2009)

The figure below explains in six steps how transactions on blockchain are performed.

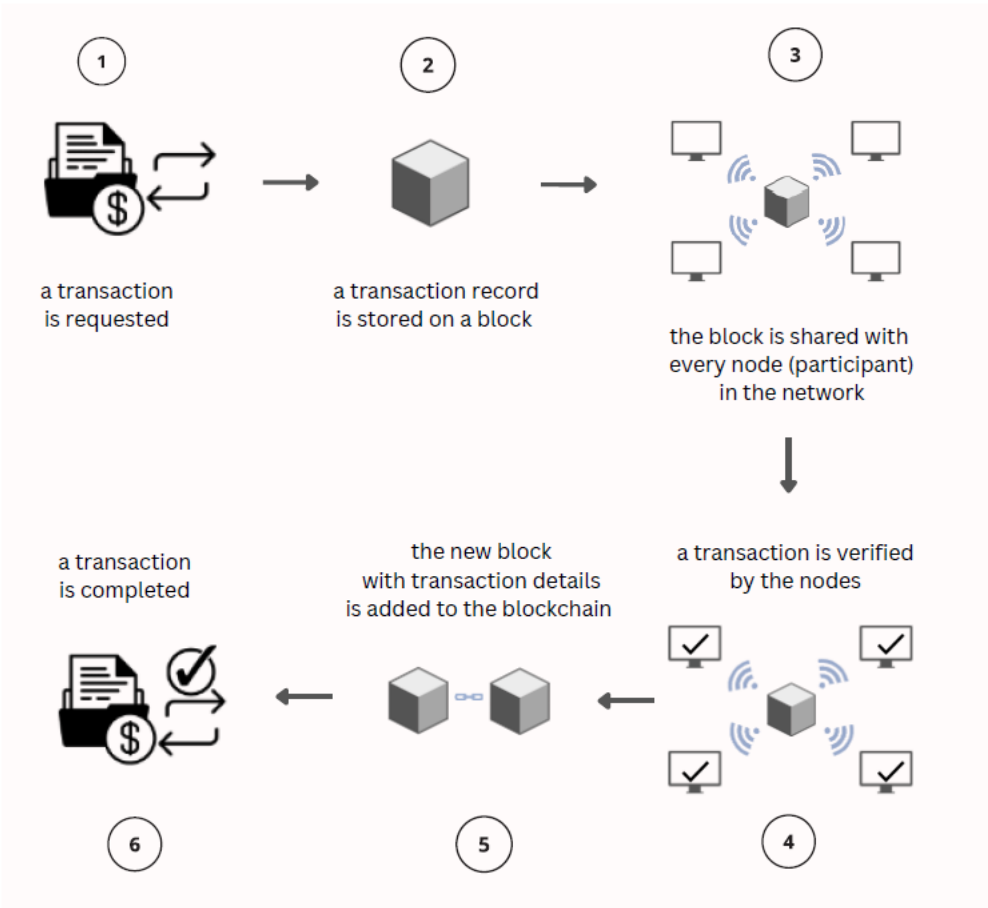

Figure 4

Blockchain transactions.
(Source: own creation, based on Pranto, Noman, Mahmud,, & Haque, 2021; Raja Santhi & Muthuswamy, 2022; Yadav & Singh, 2019)

Although, understanding how BCT works do not seem easy, a blockchain is simply a type of database for recording transactions and such database is copied to all of the computers in a participating network (Grewal-Carr & Marshall, 2016). The distributed ledger technology displays all the transactions whenever a blockchain is extended by each additional block to represent the transaction history (Nofer et al., 2017)

3.1.3. Blockchain in Business Context

The BCT can be independently applied virtually in many different industries, dealing with transactions and where assets are managed (Sultan, Ruhi, & Lakhani, 2018). The participants of the blockchain integrate their programs, and later develop and distribute their code, they shape their environment, which creates an open and adaptable system (Seebacher & Schüritz, 2017).

When BCT is applied in business, there occur benefits of cost and time savings. A business can utilize BCT in a personalized manner, changing the conditions of a specific blockchain and capitalizing only on the enforcement of the system created such as cost reduction, high security, and the ability to record. BCT can be seen as an innovation ecosystem that can be also applied in private or semi-private settings *"where the main objective is to diminish market uncertainties and asymmetry of information between agents"* (Torres de Oliveira, 2017, p. 6).

BCT may alter many assumptions about market transactions, and as a result of blockchain implementation, market agents will be forced to redesign their interactions with each other. Blockchain is about to dramatically reduce transaction costs due to extensive reduction of the middleman and describes blockchain as a framework technology that can be potentially applied in a breadth of settings (Torres de Oliveira, 2017).

BCT transforms traditional business activities by streamlining processes, increasing trust, and saving time and costs for organizations. A blockchain transforms international business practices and it is likely to influence the rules and norms, affecting global governance. This technology enables organizations to operate outside of currently set laws and governance mechanisms. Moreover, with the application of blockchain, fraud risks, and data security are supposed to be reduced as a result of data not being managed by centralized entities (Hooper & Holtbrügge, 2020).

The type of blockchain depends on the platform's characteristics and how it is managed depends on the desired objectives to be achieved. Ganne (2018) distinguishes blockchains as permissionless (accessible and open to everyone) and permissioned (restricted and not accessible by everyone, with the restrictions occurring on who can read and write on the blockchain). Another classification is made to classify blockchain as public (where no specific entity is used to manage the platform) and private (where the platform is managed by a single entity or is controlled by a consortium of companies).

In the field of international trade, BCT falls into the category of permissioned/consortium blockchain. This type of blockchain is commonly named distributed ledger technology (Ganne, 2018).

3.1.4. Blockchain Attributes

Key Characteristics of Blockchain:

Security

One of the blockchain's key characteristics is security. This technology provides a secure chain of custody for the assets (digital and physical) due to its functional characteristics enabling transactions - such as trust, consensus, and security (Sultan et al., 2018). The application of blockchain results in increased security (Torres de Oliveira, 2017), and its features are used to solve problems related to the security of networks and their users (Taylor et al., 2020; Zheng, et al., 2018).

Decentralization

Another principle is decentralization, meaning that no central authority controls the blockchain (Belu, 2019; Sultan et al., 2018). *Blockchain is "stored in a file that can be accessed and copied by any node on the network" (*Sultan et al., 2018, p.53*) and, as a* distributed database, each party on a blockchain can access the entire database, and its history and directly verify the records of the transactions without an intermediary and there is no single party controlling the data. (Iansiti & Lakhani, 2017). The BCT eliminates the need for an intermediary to perform any operation or process the data and the information involved in the operations carried out on the blockchain is permanently stored there. Data does not pass through any centralized point so there is no point of potential vulnerability on the blockchain network, hence there is no chance for data to be manipulated. All that means that the transactions conducted on a blockchain network are safe and transparent (Nakamoto, 2008).

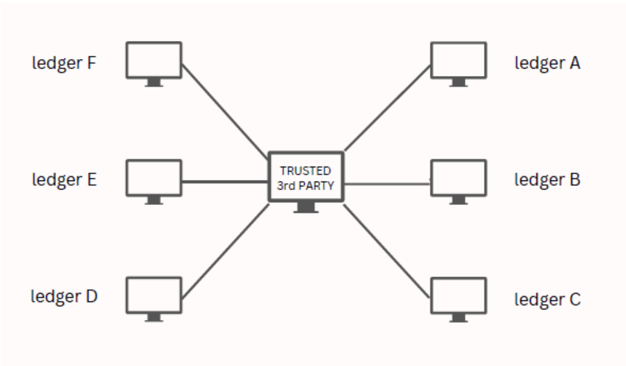

Figure 5

Traditional (centralized) network.
(Source: own creation, based on Shyamala Devi et al., 2019; Lacity, 2018)

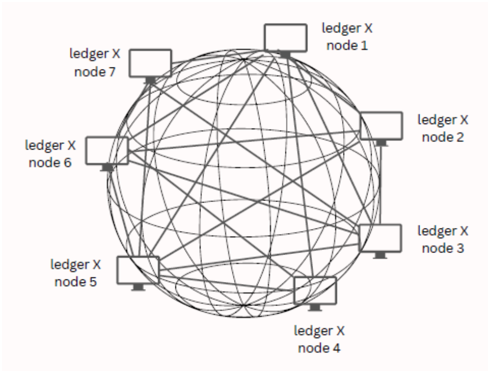

Figure 6

Blockchain distributed network.
(Source: own creation, based on Shyamala Devi et al., 2019; Lacity, 2018)

Immutability

Immutability describes the infeasibility to modify or delete information in the system; (Belu, 2019). Once a block is added to the blockchain it cannot be modified. This makes blockchain tamper-proof. As any record of the transaction on a blockchain is permanent, it results in trust in the transaction record *(*Sultan et al., 2018). All data and transactions on a blockchain are cryptographically signed, and there is no central server, meaning that the risk of network hacking and data manipulation is low. (Pavlic Skender & Zaninovic, 2020)

Transparency

Transparency with pseudonymity is another principle on blockchain describing that every associated value of a transaction is visible to anyone in the system. (Belu, 2019; Iansiti & Lakhani, 2017; Seebacher & Schüritz, 2017). Users can provide proof of their identity or remain anonymous. Once a transaction is registered in a database, the records cannot be changed as they are linked to every previous transaction with the use of different algorithms and that is called the "irreversibility of records". These computations ensure the permanent, chronological, and available to all the network participants' recordings on the database (Iansiti & Lakhani, 2017).

Blockchain provides data transparency, which assures that stored information is authentic. Every participant of the blockchain retrieves controlled access to a shared database which is a reliable source of trusted information (Heutger & Chung, 2018, cited by Pavlic Skender & Zaninovic, 2020). Any party can access this open ledger to audit and track the history of all transactions (Sultan et al., 2018). Because the blockchain has a nature of a digital ledger, all transactions are tied to a "computational logic" and can be programmed. This principle of a blockchain allows users to set up algorithms and rules and automatically fulfill transactions (Iansiti & Lakhani, 2017). Every transaction on the blockchain is recorded with a timestamp, hence users can verify and trace back previous records by accessing any node in the network (Zheng et al., 2018).

Trust Verification

Trust Verification describes blockchain as consensus-driven, where each block is independently verified with the use of consensus models which provide rules for validating a block, utilizing computing power to validate the adequate effort. There is no need for a use of central authority or an explicit trust-granting agent (Sultan et al., 2018).

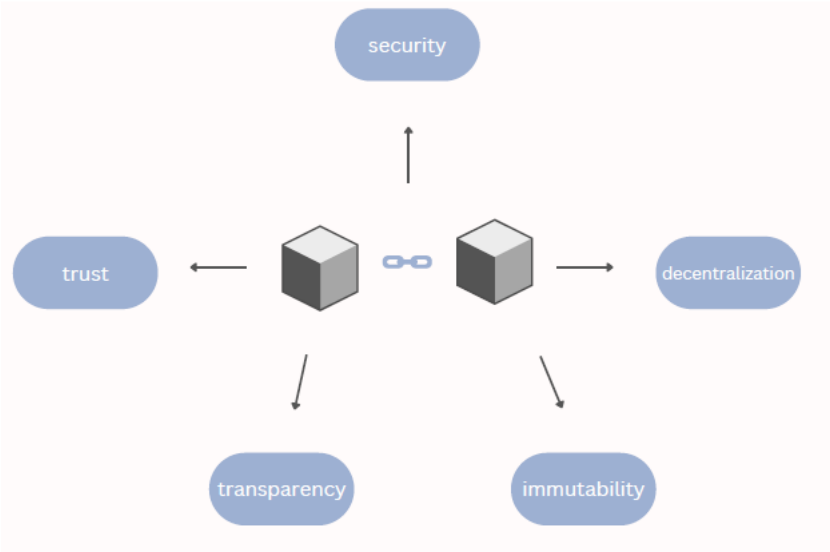

Figure 7

Blockchain Attributes.
(Source: own creation)

3.1.5. Smart Contracts

A smart contract is a contract written in a computer language that is automatically executed by a machine (De Caria, 2017) or *"a computer program that directly controls digital assets"* (Buterin, 2016, p. 3). The first definition of a smart contract occurred in the publication of Szabo (1994), where he identified a smart contract as *"a computerized protocol that executes the terms of a contract"* (p. 1). It is also referred to as a digital protocol applied to automatically execute, verify or enforce contracts when specific contract conditions are met (Hooper & Holtbrügge, 2020).

Blockchain technology enabled the functioning of smart contracts (Lage, Saiz-Santos, & Zarzuelo, 2021) and most smart contract operations are based on BCT (Ndiaye & Konate, 2021). Smart contracts are perceived as the most transformative blockchain application (Dobrovnik, Herold, Fürst., & Kummer, S, 2018). If there is no central database of registers, a blockchain-based smart contract is referred to as a "decentralized smart contract" (De Caria, 2017).

Blockchain technology is typically used to establish a decentralized system where the system is usually implemented with the use of smart contracts. Smart contracts are similar to traditional legal contracts, but the smart version compresses specific logical rules of the system and consequently guarantees their enforcement through automation (Juma et al., 2017).

Although smart contracts performed on blockchain depict some benefits over traditional contracts, fundamentally, they are still contracts. Organizations can program smart contracts to meet their particular needs, with a wide range of conditions and inputs, and: *"[. . .] these inputs can trigger the preprogrammed protocols stored on a blockchain to automatically carry out a range of actions such as executing financial transactions or sending commands to smart devices"* (Murray, Kuban, Josefy, & Anderson, 2021, p. 9).

Smart contracts digitize paperwork procedures and they maintain the consistency of transactions. They perform specific actions once particular, pre-defined conditions are met (Wee Kwan & Sundarakani, 2021). They acquire external information and automatically execute the orders agreed upon by the stakeholders (Ndiaye & Konate, 2021; Pavlic Skender & Zaninovic, 2020). A smart contract is a form of decentralized automation. Once the involved parties have reached an agreement and met its conditions, the rights and obligations of the smart contract are automatically executed by a computer. This is achieved through a built-in code of a smart contract that automatically verifies whether the pre-defined rules are fulfilled (Chang, Iakovou, & Shi, 2020).

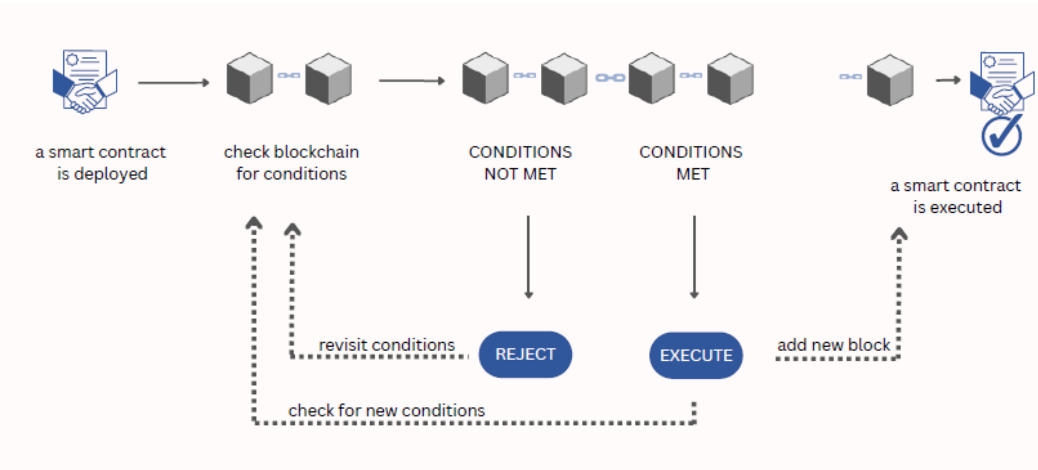

Figure 8

(Source: own creation, based on Jabbar et al., 2020)

Smart contracts are self-executing, meaning that they track transactions in real time, which reduces the paperwork and errors in the documents. All relevant parties can access the terms and conditions of smart contracts, therefore the miscommunication or misinterpretation of the parties is limited. Because all records of a smart contract are linked through hashes and they are encrypted and stored in a blockchain, it is very difficult to modify them, as it would change the whole chain if a single transaction would be altered (Chang et al., 2020). When information is added to the blockchain, it can also be identified with the use of cryptography-based digital signatures (Nikolakis, John, & Krishnan, 2018).

The application of smart contracts results in cost savings; speed and accuracy; transparency and trust; higher security and storage (Chang et al., 2020; Hooper & Holtbrügge, 2020). Such characteristic limit bureaucracy and human intervention at the same time mitigating threats of incorrect manual interventions (Wee Kwan & Sundarakani, 2021).

The blockchain smart contracts exist in a decentralized architecture, where their execution is done in a trusted manner agreed upon by all the executing participants (nodes) (Al Breiki, & Muhammad, Khaled, & Davor, 2020). Nevertheless, it is important to mention that even though smart contracts are executed in a decentralized and trustless architectures of blockchain, they are not able to access data directly from the external world. Therefore, a smart contract needs to interact with an external data sources, existing outside the blockchain – oracles, collecting and providing external data to smart contracts (Al Breiki et al., 2020).

Oracle is a system providing blockchain with information coming from the real world. In cases when smart contracts deal with mechanism involving external circumstances, such as weather, a 'portal' from the external world is necessary. The reliability of data coming from the real world, oracle, is undisputed for all nodes on the blockchain, in order for blockchain to reach consensus. Otherwise, the nodes would identify the information coming outside the blockchain as an 'untrusted' source (Caldarelli, 2020).

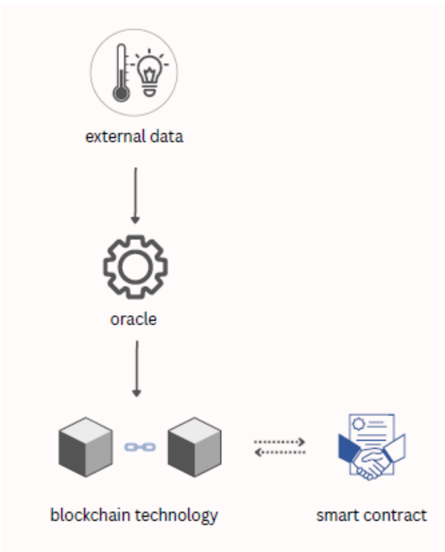

Figure 9

(Own creation, adapted from Al Breiki et al., 2020)

3.1.6. Blockchain and Supply Chain (Management)

A supply chain *is "a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flow of products, services, finances, and/or information from a source to a* *customer"* (Mentzer et al., 2001, p. 4) and/or a *"set of independent, discrete and, to a large degree, autonomous events controlled by actions related to marketing, production or distribution*" (Osmolski & Zhuravskaya, p. 4). Supply chain management is simply managing these flows to create value for the entities involved in the supply chain and for the end customer (Nayak & Dhaigude, 2019).

In the nearest future, blockchain will ultimately change how the world works and supply chains would be related to digitization aspects and processes occurring within them (Osmólski & Zhuravskaya, 2020).

Blockchain can be used to track and monitor assets, to process contracts and transactions between consenting parties (Wee Kwan & Sundarakani, 2021) storing them in 'blocks' of information, which are then connected creating 'chains' of information (Okorie & Russell, 2021), working as an interaction agent between the parties with no need for reliance on a centralized organization (Wee Kwan & Sundarakani, 2021).

BCT improves the economic performance of a firm's supply chain (Saberi, Kouhizadeh, & Sarkis, 2019a), as it affects upstream and downstream flows of information in a trusted and transparent manner, positively contributing to management practices, better customization, and reducing costs (Nayak & Dhaigude, 2019). BCT supports transparent data sharing, improving supply chain transparency and traceability (Francisco & Swanson, 2018; Parmentola, Petrillo, Tutore, & De Felice, 2022; Pavlic Skender & Zaninovic, 2020). It betters the flow of materials and information and all the involved parties can access the stored records at any time. Blockchain can be used as a tool for asset management as it enables traceability of an asset and its tiles or rights (Pavlic Skender & Zaninovic, 2020).

Yadav & Singh conducted an analysis comparing traditional and blockchain-based supply chains, taking into account common characteristics. The outcome of the study states that the integration of blockchain in traditional supply chain management is more efficient due to data safety, data management and quality, decentralization, accessibility, and documentation (Yadav & Singh 2020). The features of blockchain contributes to creating a more responsive supply chain, which in turn would result in the improvement of efficiency of supply chain processes, the quality of products and services, creating a competitive advantage (Munir et al., 2022).

Due to its distributive structure every blockchain has the potentiality to be applied to variety of needs of a specific asset, network or supply-chain. BCT can connect numerous providers through complex, globally distributed supply chains. That would also benefit reducing costs of paperwork and transportation (Okorie & Russell, 2021), benefitting big, complex, and global supply chains by providing a good end-to-end visibility. The members of a blockchain network would be given a tool to continuously validate the issues throughout the supply chain (Martino, Stone, & Ozadali, 2020).

This disruptive technology for the operations and general management of supply chains would make transactions on a global scale decentralized and transparent among many parties involved (Direction, 2021; Saberi, Kouhizadeh, Sarkis, & Shen, 2019b). It would also provide the authenticity of information and a trustless environment based on smart contractual relationships (Saberi et al., 2019b).

Blockchain creates an open access to the digital ledger of tagging and registering the goods throughout the whole supply chain, enabling supply chain mapping (Khan, Mubarik, Kusi-Sarpong, Gupta, Zaman, & Mubarik 2022). Furthermore, it enables physical items or documentation to be transferred to smart property (Balaji, 2019) enabling their originality and authenticity validation.

Blockchain enables information sharing across all channels, which leads to better inventory tracking across the supply chain (Kaur, 2019).

3.2. Sustainability

3.2.1. Sustainability in Supply Chain Management

The term "sustainability" is an extensive concept, remaining open to many interpretations and context-specific points of view. However, most often it refers to three interlinked pillars of economic, environmental, and social factors (Palazzo & Vollero, 2021; Purvis, Mao, & Robinson, 2019).

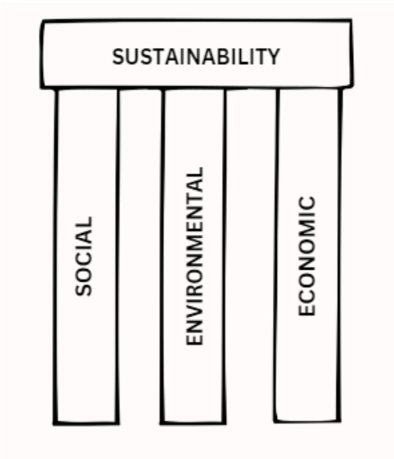

Figure 10

Three pillars of sustainability (Own creation, adapted from Pulvis et al., 2019)

To strengthen the pillars of sustainability, the environmental protection, economic and social development need to be addressed by the collective responsibility at the local and global level (United

Nations [UN], 2002). The main targets of Agenda for Sustainable Development Goals towards 2030 are people, planet, prosperity, peace and partnership. It calls all countries and stakeholders to act in collaborative partnership in order to reach this agenda (UN, 2015)

Organizations are seeking ways to meet sustainability criteria and are implementing sustainable practices due to environmental regulations and rules, and customers' demand for sustainable products is seen as an incentive to improve innovativeness in the implementation of sustainable methods within organizations (Saberi et al., 2019b).

The big number of stakeholders make supply chains complex, difficult to monitor and control sustainability problems in their vast networks (Venkatesh, Kang, Wang, Zhong, & Zhang, 2020), hence coordination among participants of the supply chain is needed (Shingh, Kamalvanshi, Ghimire & Basyal, 2020). Sustainable supply chain need to be built on the cooperation of companies in the supply chain at the same time acting towards the three pillars of sustainable development (Seuring & Müller 2008).

Sustainable supply chain *"refers to the ways in which organizational innovations and policies in supply chain management are considered in the context of sustainable development"* (Allaoui, Guo, Choudhary, & Bloemhof, 2018, p.1). Sustainable supply chain management *"ensures smooth supply chain operations, focusing on social, economic, and environmental goals"* (Fu, Abdul Rahman, Jiang, Abbas, & Comite, 2022, p. 1).

The implementation of means towards sustainability include a selection of sustainable suppliers, the design of a sustainable supply chain network, the implementation of sustainable information technology, sustainable manufacturing, sustainable purchasing, and sustainable freight transportation (Allaoui et al., 2018).

To attain supply chain sustainability, companies should produce and deliver their goods in a way that is sustainable, not negatively impacting the environment and social inequalities (Pavlic Skender & Zaninovic, 2020), taking into account economic, social and environmental factors (Zdziarska & Marhita, 2020).

One of the issues regarding sustainability in supply chains is the ability to verify whether products and processes meet sustainability criteria and certifications. The key to solving this challenge is to improve supply chain transparency and security (Saberi et al., 2019b).

3.2.2. Blockchain for Sustainability

The most potent digital application to improve sustainable development is BCT (Balakrishna & Kumar, 2020; Upadhyay, Mukhuty, Kumar, & Kazancoglu, 2021; Van Rijmenam & Ryan, 2018). BCT has the potential to create a balance between the environment, economy, and society, where the goals of sustainability and social responsibility can be achieved (Upadhyay et al., 2021).

The United Nations Climate Change (UNCC) (2018) emphasizes the potential of disruptive technologies such as BCT in contributing to social and environmental sustainability. Blockchain with the distributed ledger technology could "*strengthen monitoring, reporting, and verification of the impacts of climate action; improve transparency, traceability and cost-effectiveness of climate action; build trust among climate actors; make incentive mechanisms for climate action [...]*." (p .1)

BCT can accelerate environmental protection and the key attributes of blockchain are likely to be beneficial in supporting sustainable development (Dorfleitner, Muck, & Scheckenbach, 2021; Herweijer, Waughray, & Warren, 2018; Schulz & Feist, 2021). Moreover, data transparency and many access points on blockchain contribute to the international and cross-sectoral exchange of goods that are also related to minimizing CO2 emissions (Dorfleitner et al., 2021).

BCT enables sustainable food production and reduces waste and emissions in the product journey by utilization of low-carbon product design and production (Yadav and Singh, 2020) also reducing the use of non-renewable energy (Sankaran, 2019).

BCT could be used for tracking energy production; energy consumption (Imbault et al., 2017; Yadav & Singh, 2020), CO2 emissions; and green certificates - which is *"a kind of commodity product that serves as a proof that the electricity has been generated from renewable energy sources, such as solar or wind."* (Imbault, Swiatek de Beaufort, & Plana 2017, p. 3)

BCT helps in facilitating new means of green production, analyzing and storing data-related activities about environmental degradation (Parmentola et al., 2022). Blockchain-based life cycle assessment creates more sustainable products and delivers data for green marketing (Kouhizadeh and Sarkis, 2018).

BCT has a significant role in creating a sustainable society (Mora et al., 2021), and enhancing corporate sustainability and sustainable manufacturing (Parmentola et al., 2022). Adopting blockchain and other digital technologies may positively influence the sustainability performance of a company as it improves manufacturing competency along with promoting organizational capabilities linked to sustainable innovation like a sustainable partnership (Ghobakhloo, Iranmanesh, Grybauskas, Vilkas, & Petraitė, 2021).

Suppliers, distributors, and customers are encouraged to use BCT as a means to achieve sustainable performance, where implementing sustainable practices by minimizing waste is seen as an organizational responsibility. BCT enables collaboration between customers and organizations to help them improve their sourcing and recycling practices (França, Neto, Gonçalves, & Almeida, 2020).

This technology is likely to transform both sustainability reporting and assurance, causing organizations to improve and demonstrate their performance and, at the same time, allowing shareholders to make better-informed decisions (Herweijer et al., 2018). With the improvement of data management, decision-making also improves and BCT can authenticate, manage and automate the use of data. Essentially, BCT provides a trust relationship between users and content. Hence, blockchain promises to aid in fighting poverty, lower inequality, empower the accountability of institutions, and increase the production of sustainable energy. It provided users with the ability to verify all transactions and settlements, with no need for a third party in the exchanges of non-financial assets; such as information, data, and identity to name a few (Van Rijmenam & Ryan, 2018).

3.3. Agri-Food Supply Chain

3.3.1. Agri-Food Supply Chain and Sustainability (Issues)

Agri-food supply chain management is a set of activities concerned about "*transforming agricultural commodities from their raw stage to consumption phase* (Ganeshkumar, Pachayappan, & Madanmohan, 2017, p. 69). Agri-food supply chains include all chains of activities from farm production to processing, distribution, and retailing (Naik & Suresh, 2018), and they also enfold acquisition of agricultural raw materials (Ganeshkumar et al., 2017).

Customers in an agri-food supply chain are identified as *"all the parties purchasing semi-processed or final products"* (Tiscini, Testarmata, Ciaburri, & Ferrari, 2020, p. 1630).

Figure 11

(Own creation, adapted from: Kamilaris, Fonts, & Prenafeta-Boldύ et al., 2019)

In comparison to other supply chains, agricultural supply chains are more difficult to manage as they deal with food safety, food quality, and limited shelf life and they need to attain stable networks and relations between suppliers, producers, processors, traders, and retailers (Sodamin et al., 2022).

The agri-food supply chain system has many levels of transactions, with different terms and conditions and all of them include records of all the steps from the long and complex product journey (Bhat et al., 2022). Transactions in agri-food supply chains are complicated and risky, relying on many intermediaries. They struggle with transparency and efficiency issues, putting farmers and consumers at a disadvantage (Tripoli & Schmidhuber, 2018).

Every product in the agri-food supply chain has a long and storied history, but much of it is hidden due to its harmful practices, and it is not easy to attain information visibility (Motta, Tekinerdogan, & Athanasiadis, 2020).

In a global context, agri-food production is responsible for almost one-third of greenhouse gas emissions (Crippa et al., 2021) consuming approximately 30% of the total energy (Dayioglu & Turker, 2021; Food and Agriculture Organization of the United Nations [FAO], 2023a), and consumes more than 70% of the world's resources of fresh water (Liu, & Shang, 2022).

There exist food adulteration and a lack of openness in the agri-food supply chain (Bagwasi & Raja, 2020) with a low level of automation, lack of industrialization, inconsistent and fragmented information, and food safety issues that result in inefficient supply chains (Mukherjee, Singh, Mishra, & Bag, 2022). These issues have caused a significant rise in food loss (Singh, Luthra, Mangla, & Uniyal, 2019), delayed payment, and high transaction costs due to the presence of many intermediaries (Mukherjee et al., 2022).

A big issue in the agri-food supply chain is food waste (Sodamin et al., 2022; Wünsche & Fernqvist 2022) where about one-third of all food produced is lost or wasted globally (Wünsche & Fernqvist 2022). This matter has severe implications for firms' inefficiencies in the food chain and it is costly for society as the resources are wasted (Wünsche & Fernqvist 2022). It is highly important to reduce food loss and wastage across food supply chains as well as to improve the storage and distribution condition of the products (Kaur, 2019).

Taking into consideration the majority of transactions in the supply chains, the complexity of them relates to a lack of transparency and the asymmetry of information (Pavlic Skender & Zaninovic, 2020; Sodamin et al., 2022), slow information flow, costly paperwork, duplication of procedures (Pavlic Skender & Zaninovic, 2020) inefficient transactions, fraud, costly and not reliable intermediaries (Saberi et al., 2019b).

Therefore, it is crucial to make supply chains transparent with advanced traceability and information exchange among stakeholders. That would result in better management of sustainability matters and create trust among the participants of global supply chains (Munir et al., 2022; Saberi et al., 2019b; Sodamin et al., 2022; Venkatesh et al., 2020).

3.3.2. Agri-Food Supply Chain and Food Safety

Contamination of food products is dangerous to the food supply, hence it is crucial to undertake any measures to eliminate this risk. The parties in the food industry and regulatory agencies should ensure that all food products are correctly labeled and prevent the entry of unsafe food products into the marketplace (Martino et al., 2020).

A solution for achieving food safety is to attain food traceability, identified as *"the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution, and sales or internally in one of the steps in the chain."* (Curto & Gaspar, 2021, p.680).

According to Regulation 178/2002 of the European Commission (EC) 2002, food traceability is *"the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated in a food or feed, through all stages of production, processing and distribution"* (EC 2002, Regulation 178/2002, p. 31/8).

Internal traceability relates directly to the product and the information about the product within the company, while external traceability relates to the information about the product received from other supply chain members. Traceability regulations demand from food businesses to be within the control of tracking food back and forward within a food supply chain (Ababouch, 2007).

A key to assessing whether a food product is safe would be the use of food authentication. It is *"a process by which the compliance of foods with their label descriptions (e.g., geographic origin, production method, processing technology, composition, etc.) is verified"* (Galvez et al., 2018, p. 224). This process can trace back to whether the food contains banned or toxic ingredients and at the same time protects it from food fraud which poses threats to human health (Galvez et al., 2018).

Traceability and transparency enable customers and buyers to verify and validate the origins of the food products, at the same time, allowing business stakeholders, authorities, governmental agencies, and consumers, to manage and respond to risks in a responsive and documented way (Chang et al., 2020).

Many food products are mixed in the supply chain and their identification can be easily lost, meaning that it is highly important to track and verify them at any given step. The concept of traceability of products must be applied at any stage of the food supply chain, tracking products from production to distribution. In such a case, all actors in the supply chain can identify their suppliers and see when and where exactly their food is sold. This solution would connect all tied supply chain members (Bhat et al., 2022).

Food falsification results in economic losses (Galvez et al., 2018). Compliance data and documentation of food safety and sustainability are usually stored on private databases, and can only be accessed by third-party authorities. That causes a need to enable information transparency and build trust among stakeholders in agri-food supply chains (Motta et al., 2020).

3.3.3. Agri-Food Sector and Sustainability (Issues)

The agri-food sector refers to *the "production, processing, and inspection of food products made from agricultural commodities."* (McCarthy, Liu, & Chen, 2016, p. 3), and "*the agri-food sector is composed of both agriculture & farming and food processing activities"* (EC, 2020, p. 5).

Activities related to food production use a significant amount of water and energy, where water, energy, and food are identified as strategic resources for the sustainable development of economies (Dayioglu & Turker, 2021).

The agri-food sector negatively affects the environment and contributes to climate change. A sustainable food future takes into account food quality and security; soil and water management; drought, heat; flooding; diminishing yields; and compromised food security. At the same time, consumers are getting aware of ethical and sustainable consumption and investors demand more accurate data in food supply chains (Wünsche & Fernqvist 2022).

Numerous sustainability concerns are related to food production (Kaur, 2019; Sonnino et al., 2014). Preventing food waste and ensuring food availability through sustainable agriculture practices from farms to end consumers is needed (Kaur, 2019).

Many businesses are entering the agri-food sector with the aim to measure production parameters, such as water use, soil enzymes, and pesticides, to enhance sustainability (Wünsche & Fernqvist, 2022).

Climate change adaptation in agriculture aims to lower the vulnerability associated with the impacts of climate change, where its negative impacts include the loss of social-economic welfare among food producers (Donatti, Harvey, Martinez-Rodriguez, Vignola, & Rodriguez, 2019) and the loss of agri-ecosystem services and biodiversity for food and agriculture (Van Wassenaer et al., 2021).

There is stakeholder pressure on agricultural firms to adopt sustainable practices and to be environmentally responsible for highly increasing production and distribution of food products (Allaoui et al., 2018; Naik & Suresh, 2018)

To face climate change, sustainability in the agricultural production system needs to be addressed. Technological advancement would serve the purpose of improving efficiency in production, at the same time reducing the environmental impact of food production (EC, 2020). Traceability, security, and immutability of information are highly beneficial in the agri-food sector, improving its sustainability. It eliminates the need for intermediaries and in turn reduces transaction costs (Mercuri, della Corte, & Ricci, 2021).

To achieve an optimization of the food supply chain, agriculture needs to be revitalized (Iitsuka, Fujii, Kokuryo, Kaihara, & Nakano, 2019).
Food security is affected by environmental conditions as any change in climate affects the quality of the crops (Kaur, 2019).

3.4. Blockchain for Sustainability in Agri-Food Supply Chain

BCT is seen as a helpful tool in the adaptation of sustainable agricultural practices and achieving climate change mitigation (Van Wassenaer et al., 2021). The research, development, and application of blockchain technology in the area of traceability in agri-food are gaining momentum (Pincheira et al., 2021) and its main purpose of application in agriculture is to enhance traceability and transparency throughout the agri-food supply chain (Leduc et al., 2021; Feng, Wang, Duan, Zhang, & Zhang, 2020; Kennedy, Stitzinger, & Burke, 2020; Okorie & Russell, 2021; Shingh et al., 2020).

Transparency, traceability, and efficiency are the major aspects of the agricultural supply chain, positively affecting farm-to-market flow (Lakkakula, Bullock, & Wilson, 2020), improving its performance, and creating a foundation to loyalty between members of the agri-food supply chain (Motta et al., 2020).

Blockchain is seen as an excellent mechanism for sharing information in the agriculture sector (Munir et al., 2022), creating information symmetry among the stakeholders of the agricultural supply chain, improving supply chain management, food safety, and sustainability (Mukherjee et al., 2022).

Kaur (2019) states that to build a sustainable food security system, technologies need to be integrated and the application of smart contracts is proposed to ensure transactions between stakeholders.

Smart contracts can help facilitate all the complex processes along the product journey and they can track the goods, inventory, and ownership throughout the whole supply chain (Bhat et al., 2022), involving all relevant participants e.g. farmers, growers, food processors, wholesale and retail outlets, and end consumers (Lakkakula et al., 2020) and enabling them to trust the information stored in the ledger (Norberg, 2019).

BCT improves monitoring practices of the sustainable supply chain, especially in the agri-food industry (Parmentola et al., 2022) and it allows all the connected nodes of the system to verify and maintain the data records (Mercuri et al., 2021; Raboaca, Bizon, Trufin, & Enescu, 2020).

This technology would inform farmers about the recent issues within the agri-food supply chain, making the chain more transparent and would help the agricultural industry to produce high-quality food, at the same time having a lower negative social and environmental impact (Sodamin et al., 2022).

BCT can make the agri-food supply chain shorter and more transparent which would improve farmers' position and contribute to the development of their community customers can verify whether working conditions are ethical and sustainable (Wünsche & Fernqvist, 2022)

Blockchain enables building trust among stakeholders in agri-food supply chains. (Motta et al., 2020; Mukherjee et al., 2022; Okorie & Russell, 2021) and minimizes transaction costs (Mukherjee et al., 2022). Also, it minimizes fraud and product adulteration and improves supply chain security and real-time data tracking of agricultural products. (Mukherjee et al., 2022; Sodamin et al., 2022), at the same time detecting inefficiencies along the supply chain (Sodamin et al., 2022).

Consumers would be able to make more informed decisions about the products they purchase while fairness and transparency of provided information would result in building consumer trust (Okorie & Russell, 2021; Sodamin et al., 2022).

BCT enhances data security in agri-food supply chains. It enables customers to track the history of a food product from production to distribution. They also can monitor sustainable practices in processing agri-food products, such as water consumption and compliance with regulations. When dealing with BCT in an agri-food supply chain, customers become part of the informative chain and they are also used for market data analysis (Tiscini et al., 2020).

3.4.1. Blockchain for Food Safety in Agri-Food Supply Chain

Many systems based on BCT were developed to support food traceability in a supply chain, where they assess the availability and originality of an agricultural commodity (Sivianes & Bordons, 2021). BCT is used to store and validate the records of food information along the chain in a safe and impossible-to-manipulate manner (Galvez et al., 2018).

Lin, Shen, Zhang, & Chai (2018) show how to address food safety issues from the technical aspect, proposing a trusted, open, ecological, and self-organized food traceability system based on blockchain technology, including all parties from the smart agriculture ecosystem. The system enables tracking and monitoring the whole lifespan of food production, starting with food raw material cultivation/breeding, processing, transporting, warehousing, and selling.

When a food product is transferred to a smart asset (digital product), information about a farm's origin, production method, batch number, processing technology, shipping details, and storing temperatures is digitally connected to a physical food product and all the information is recorded on a blockchain at every step of the product journey throughout the supply chain. The specifics of the information provided in each transaction along the supply chain need to be agreed upon by the participants of the chain to reach a consensus, where no record can be altered (Galvez et al., 2018).

At the end of the food journey, all the details about the product are stored on a blockchain including all the information about the lifetime of the food product. Such information can be used to prove the quality and sustainability of the product (Galvez et al., 2018).

BCT can store and share information about the humidity and temperature of the food products during transportation and storage and it can be captured along the whole supply chain. Furthermore, BCT would enable the application of individualized perishability dates, which would be specifically set up to the condition of food production, storage, and transportation of a particular food product. That would help prevent food waste, ease the distribution of perishable foods, and minimalize the outbreak of foodborne diseases (Wünsche & Fernqvist, 2022).

BCT can be also used to support ways of risk prevention, concerning health risks and food waste, at the same time identifying possibilities for sustainable by-product management. (Okorie & Russell, 2021).

Efficiency in the supply chain is crucial to limit food losses as it reduces food spoilage and reduces the time needed for the food to reach the final consumer (Lakkakula et al., 2020). If all the farmers, processors, retailers, and regulators would have access to a trusted network based on BCT, the spread of foodborne illness could be limited. Every participant in a network could immediately stop the spread of illness and save their customers by accessing information about the exact origin and journey of a food product (Pavlic Skender & Zaninovic, 2020). Once contaminated produce is identified, other items coming from the same source can also be removed, as high-risk products, before they reach a final customer (Okorie & Russell, 2021).

BCT reduces the time to trace the origin in case of contaminated food products and at the same time reduces the costs of pulling product, storage, and disposal (Lakkakula et al., 2020), enabling quick investigation and tracebacks of microbiological analysis to draw epidemiologic conclusions (Kennedy et al., 2020).

BCT would benefit from labeling of a food product with a QR code, where a customer could verify details about the product from production to the end of a product journey (Alobid, Abujudeh, & Szűcs, 2022).

3.5. Blockchain for Sustainability in Agri-Food Sector

I put agri-food sector because I noticed in the gathering of lit. that it has many implications for farmers and agri-food sector plus organic farming is directly related to sustainability. I did not go much in depth- but tried to keep my research in this topic connected to the agri-food supply chain activities.

BCT could contribute to the improvement of the agri-food sector, by making food supply chains integrated and transparent, and it could positively contribute to the safe production of quality food, minimizing social and environmental impacts (Rana, Tricase, & De Cesare, 2021).
BCT helps in a transition towards more data-driven agriculture (Wünsche & Fernqvist, 2022), improving market data analysis, financial efficiency, organic farming, and labeling (Tiscini et al, 2020). It provides farmers with access to agricultural services which in turn overcomes problems related to policies, regulatory frameworks, technical aspects, and accessibility (Raboaca et al., 2020).
Blockchain application in this sector is related to risk management; anti-corruption; digital product passports; data passports; monitoring the use of pesticides; biodiversity index; natural capital, among others (Van Wassenaer et al., 2021).

BCT opened the door for the development of sustainable electronic agriculture which is based on BCT and IoT. It makes the production and sales of agriculture more intelligent, creating a form of an information revolution and creating a diversified network of networks around the world (Li et al., 2020).

Climate-smart agriculture, based on blockchain technology, is a concept that transforms agricultural systems to support and develop food security, dealing with sustainable agricultural productivity, creating resilience to climate change, and reducing greenhouse gas emissions (FAO, 2023b). They provide farmers with information about weather, water floods, and scarcity, most weather-adaptable crop seeds and animal breeds, how to limit gas emissions, and how to contribute to socio-economic practices (Van Wassenaer et al., 2021).

Furthermore, blockchain enables the use of a smart farming system, which stores sensing results from sensors and cameras in a globally distributed database, where farmers, food suppliers, and customers have access to it once they are connected to the network. Such application of blockchain and other intelligent technologies would provide farmers with digital tools to measure the temperature, PH, acidity, and moisture of agricultural soil, which would lead to improved effectiveness and operational productivity in agriculture (Widi Widayat & Köppen 2021). In smart agriculture proposed by Shyamala Devi, Suguna, Joshi, & Bagate (2019), components of blockchain nodes are sensing and controlling temperature, PH moisture, smoke and fire, pressure, illuminance, wind speed, air, CO2, pressure, pollution.

All the participants of the smart farming system would be connected to a global blockchain network with a digitally assigned node account based on each of their roles, resulting in effortless transactions within the network. This global database would be synchronized, decentralized and immutable, storing and encrypting data, enabling smart contract transactions, providing food originality, and achieving trust between food producers and consumers (Widi Widayat & Köppen 2021).

BCT, safely and efficiently, uses personal and industrial data in production operations. It utilizes information without invading personal privacy or trade secrets (Yano, Dai, Masuda, & Kishimoto, 2020) and helps to manage and reduce the amount of agricultural waste during harvest and transportation (Kaur, 2019).

Raboaca et al. (2020) outline the implementation of BCT for farmer's associations and provide them with immutable databases. BCT helped them impose the regulatory framework and stop food fraud, and the traceability, security, and certification of financial processes were improved. Agriculture became more efficient enabling farmers to recycle more. With the integration of smart contracts in the blockchain, agricultural farms experienced better energy management, increased financial and economic growth and it was easier and safer to access agricultural services and resulting in better performance of the systems. Additionally, through the development of an internal economy in farmers' associations, the working environment and employment were improved, and a *pollution* reduction was recorded.

The application of smart contracts also enables farmers to sell their produce before harvest on digital platforms (Kaur, 2019). BCT could facilitate an intelligent market for soon-to-expire food, where wholesalers would sell it to retailers at a lower price, under the condition that they could sell it within a time limit (Wünsche & Fernqvist, 2022).

Leduc, Kubler, & Georges (2021) proposed a blockchain-based farming marketplace that holds the functionalities of a traditional food chain but, with the use of blockchain-based smart contracts, the platform acts like an intermediary between different stakeholders involved.

The process of delivering food and receiving payment for farmers would be quicker as delays in payments would be reduced and transactions would be done immediately without any intermediaries (Alobid et al., 2022).

BCT is also used as means of achieving better prices and payment options for farmers (Bagwasi & Raja, 2020) and electronic agriculture of BCT resulted in significantly higher farmer's sales, with a rise of 25% on average in comparison with traditional electronic agriculture (Li, Wang, & Li, 2020). Moreover, hijacking and cheating of the middlemen can be prevented, enabling the development of separate channels for farmers, enhancing their skills and their common unity, and creating more farming jobs in the organic field (Balakrishna & Kumar, 2020).

3.6. Global Perspective

This part of the study serves the purpose of explaining the global perspective of the research topic. There is not enough literature to include a global perspective for more detailed analysis in relation to the problem formulation of this research, however, it is necessary to introduce this topic as the global dimension is a part of this study and may affect the final results of the research.

Traditionally, agri-food supply chains are made of autonomous, independent actors, however, currently, they are changing into globally interconnected systems that are made of complex relationships. These relationships in the supply chains influence how food is produced, processed, and delivered to the market (Naik & Suresh, 2018). Often times foods are grown in one country, processed in another, and their distribution is spread to many national and international markets (Gourama, 2020).

The food supply chains have become complex (Astill et al., 2019), globalized (Gourama, 2020; Pavlic Skender & Zaninovic, 2020), multi-actor, and distributed (Sodamin et al., 2020), including many stakeholders (Astill et al., 2019; Sodamin et al., 2022;). For the food to reach the final consumer, farmers, processing factories, distributors, and retailers need to cooperate (Ancín, Pindado, & Sánchez, 2022; Palazzo & Vollero, 2021).

Consequently, the food security has become a global issue (Demirci et al., 2020; *;* Kaur et al., 2019; Munir et al., 2022; Pavlic Skender & Zaninovic, 2020; Widi Widayat & Köppen, 2021) and the old methods for logistics and transportation of agri-food were not matching the market's demand (Munir et al., 2022). Providing food security has become a major agenda for policymakers worldwide (Galanakis, Rizou, Aldawoud, Ucak, & Rowan 2021; Kaur, 2019) as the global dynamics is changing and the old ways of ensuring food security also need to change as they are no longer sufficient, therefore the need for the safe agri-food value chain has emerged (Munir et al., 2022).

There is immense competition in the global food market and consumers' expectations are rising. Additionally, information asymmetry, lack of data standardization, regulations (Mukherjee et al., 2022), lack of transparency in global food supply chains could cause inefficiencies, fraud, pollution, and violation of human rights (Mercuri & Ricci, 2021). The lack of transparency in global supply chains brings threat of fraud, trespassing on human rights, pollution and inefficiencies (Mercuri et al., 2021

"Food Supply Chains are center-stage in the global conversation on sustainability." (Okorie & Russel, 2021, p. 1). They link many various sectors of the economy and they contribute to the global economy and sustainable development (Palazzo & Vollero, 2021).

BCT can address the matter of food security by boosting the reliability of food supply chains in a global perspective (Bhat, Huang, Sofi, & Sultan, 2022; ; Bhattacharya, 2021; Friedman & Ormiston, 2022; Widi Widayat & Koppen, 2021).

The BCT in agriculture has become a growing trend on an international level, leading to innovations in the agricultural market (Sodamin et al., 2022) and blockchain is a technology that can "*bring hope to the agricultural supply chains*" (Bai, Quayson, & Sarkis, 2022, p. 3).

BCT could contribute to the improvement of global supply chains, especially in the agri-food sector, where this distributed ledger technology could make food supply chains integrated and transparent, and it could positively contribute to safe production of quality food minimizing social and environmental impacts (Rana et al., 2021). Data transparency and many access points on blockchain contribute to international and cross-sectoral exchange of goods (Dorfleitner et al., 2021). Blockchain could serve as an oracle to test if the goods meet particular contract requirements agreed upon in the sales contract at the port of entry and the port of destination (Lakkakula et al., 2020).

3.7. Barriers to Blockchain Implementation in Agri-Food Supply Chain and Agri-Food Sector

The agricultural industry is underdeveloped and stands in the need for digital transformation to attain food safety (Bai at al., 2022). Nevertheless, there exist many barriers to adoption of new technologies in this sector as it is still in the starting phase of digital transformation process and there is still a lack of awareness about limitations related to implementation of new technologies (Ancín et al., 2022). The transition from a traditional supply chain to a blockchain-based supply chain is not easy and straightforward as it needs much know-how and maintenance of technology (Mukherjee et al., 2022).

BCT opened the door of the agricultural sector in modern agriculture, yet smart agriculture is still in the development stage (Li et al., 2020) and even though the BCT has a great possibility to enhance agriculture, it also has various barriers to overcome (Bagwasi & Raja, 2020).

To start with, BCT is still in immaturity phase (Palazzo & Vollero, 2021; Okorie & Russell, 2021) and, currently, the majority of blockchain ecosystem implementations are pilot projects, which are carried on for a short period. It is not always known which technological aspects of BCT are applied and what their exact influence is (Van Wassenaer et al., 2021). Industries question the benefits of BCT application due to no sufficient and apparent examples of implementation of BCT into effective systems which could be used as examples to follow (Okorie & Russell, 2021).

Saberi et al. (2019) identified four types of barriers to BCT application, namely: interorganizational, intraorganizational, external, and system related. They are related to financial and managemen issues, as well as to cultural differences of supply chain members, among the others.

Okorie and Russell (2021) pointed out that the barriers for blockchain implementation in the supply chains are concerned with storage, scalability, capacity, lack of expertise, and high development costs among the others. Rana et al. (2021) identified barriers to BCT technology implementation as "*scalability, privacy leakage, high cost and connectivity problems"* (Rana et al., 2021, p. 1).

Yet the most apparent barrier to BCT adoption mentioned by scholars is high energy consumption. Blockchain utilizes very high computing capacities and it is perceived as a big concern as it negatively affects the environment (Biswas et al., 2022; Dorfleitner et al., 2021; Parmentola et al., 2022). Furthermore, the deployment of BCT is costly (Bai at al., 2022).

Another barrier for blockchain implementation are legal matters (Schulz, et al.) A successful implementation of BCT needs structural and organizational changes (Wünsche & Fernqvist 2022) and the regulations for sustainable development in agriculture needs to be developed (Li et al., 2020). Even though organizations are said to have been actively investigating BCT on a strategic level, there still occur some issues regarding regulations, standards, governance and immaturity of blockchain-based technology (Galvez, Juan, Mejuto, & Simal-Gandara, 2018; Palazzo & Vollero, 2021).

Ganne (2018) states that "the deployment of Blockchain on a large scale could also be hindered by various standards and requirements imposed by national regulatory authorities, including data localization requirements and barriers to cross-border data flows" (p. 101).

To successfully implement this technology in agriculture sector, widespread acceptance, education, training and understanding of smart technology by farmers is required. The blockchain implementation into the global supply model needs policy support and technology promotion. This is perceived as an issue because many of developing countries rely their food supply and demand on supply chains and their technical and economic resources might not be sufficient for an upgrade of their food systems, as well as not to ensure that the food in long-chain food supplies is of a high quality (Luo et al., 2022).

To develop and implement BCT, organizations would also need to overcome the issues of digital literacy and improvement of infrastructures (Esteso et al., 2021), at the same time facing high costs, as well as high risks of technical, managerial and ethical issues (Parmentola et al., 2022). Overall, general complexity of BCT hinders an effortless implementation of this technology and collaboration of the chain members is essential(Galvez et al., 2018).

Another challenge of BCT is to prove that the unique value added of BCT is superior to already existing alternatives. Traceability systems based on BCT might turn out to be less efficient than traceability systems based on centralized databases (Loklindt, Moeller, & Kinra, 2018). This leads to another barrier for the implementation of BCT which is a high level of distrust among organizations (Biswas et al., 2022). Moreover, blockchain has not attained customers' awareness of how it can benefit them in checking the product quality or organizational practices (Biswas et al., 2022).

There still exist lack of regulations and guidelines regarding sharing of data. This means that producers disclose only positive aspects of their brand, lacking the truth about their products and their impact on the environment (Wünsche & Fernqvist, 2022).

BCT should be able to inter-operate with other blockchains and other Information Technology systems (Dorfleitner et al., 2021). There is a lack of clarity on how BCT should be put into action in the food supply chains. Such action needs accumulation and/or blending of multi-sourced materials (Okorie & Russell, 2021).

Blockchain's system is limited in terms of preventing fraudulent registration of members, nevertheless it easily detects false activities performed by these members. This means that the social activity of a community is supervised by the technology, which provides cultural support for the network. However, since BCT works better to identify fraudulent information than fraudulent participants, it is argued that for BCT to be implemented in supply chains, an identity verification solution should be devised in a first place (Van Rijmenam & Ryan, 2018).

Although BCT implementation for agri-food traceability systems is getting much attention, only few practical applications are identified (Antonucci et al., 2019) and the knowledge of BCT in the agri-food context is still limited (Wünsche & Fernqvist, 2022).

4. Literature Analysis

In this chapter, the analysis of word data presented in the literature review chapter will be conducted. In this chapter, no new literature will be added. Taking into account the nature of the analysis part, a critical standpoint needs to be taken. Thus, to demonstrate a personal interpretation of this research, the following chapter will contain parts written in the first person (the researcher's) point of view.

The figure below represents the outline of the main parts in this chapter.

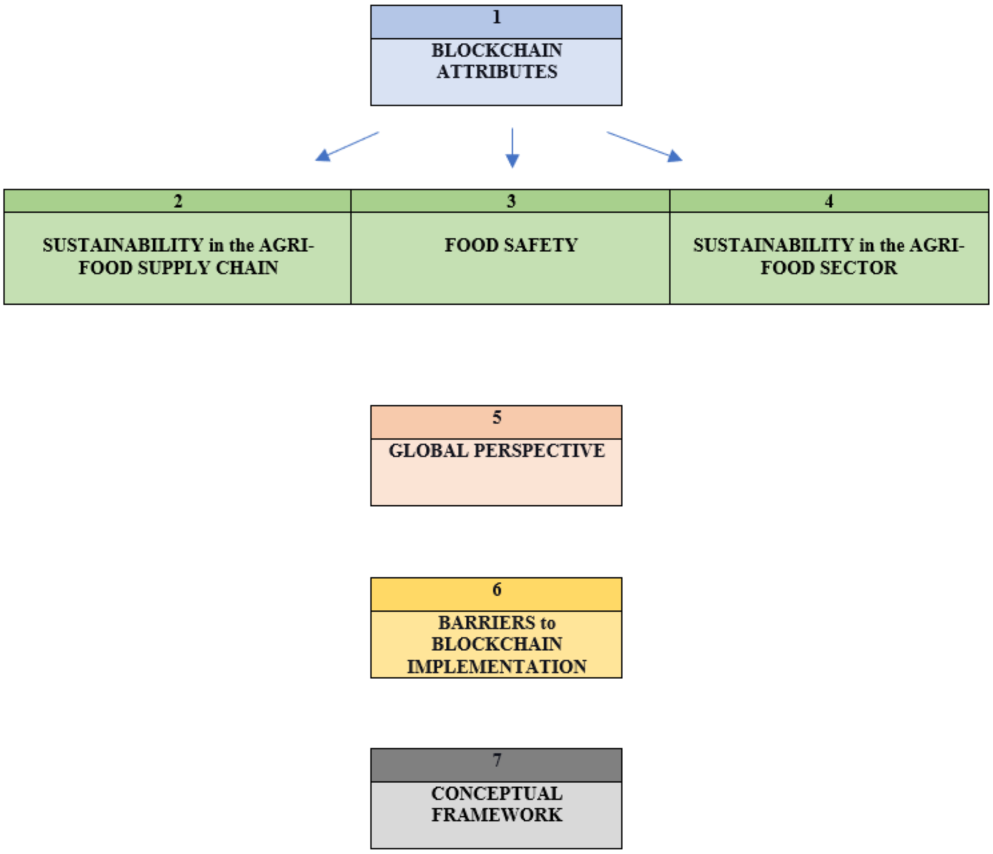

Figure 12

4.1. Blockchain

Having identified key characteristics of Blockchain Technology and their implementation in business settings, in order to answer my research questions, I will apply the attributes of Blockchain as 'lenses' through which I will examine their application in different aspects of agri-food supply chain and its effect on sustainability.

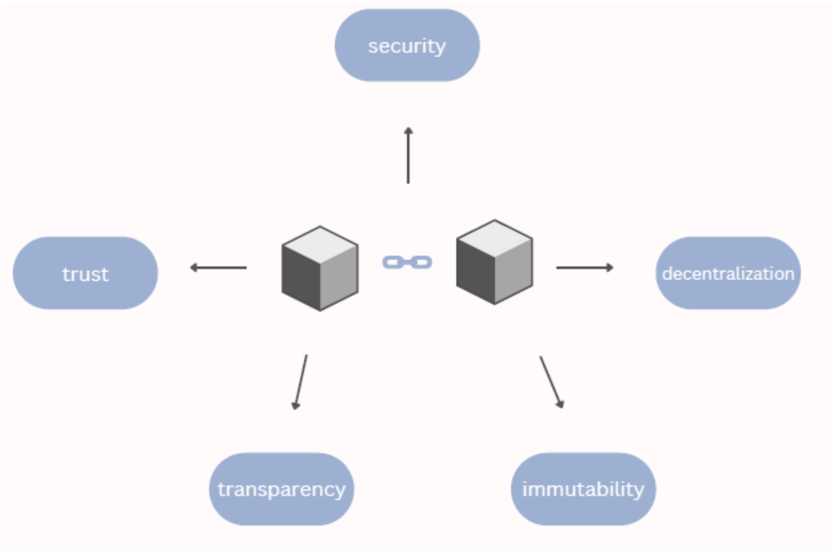

Figure 13

Blockchain Attributes (own creation)

Before covering the subject of how blockchain affects agri-food supply chain specifically, I found it necessary, to begin by describing blockchain's effect on supply chain management in general, to consequentially access which of these effects can be applied to agri-food supply chain settings. However, by analyzing data in the section Blockchain and Supply Chain (Management), I noticed that each of the possible benefits of BCT implementation in the supply chain, universally, could have the same effect on a more specified – agri-food supply chain.

Therefore, I did not identify anything relevant in this chapter. Nonetheless, I can state that deployment of blockchain in supply chain management is mostly beneficial in terms of improved supply chain transparency and traceability, data management and quality, more efficient and responsive supply chain management, and improved asset management.

4.2. Sustainability

Sustainability is based on three interlinked pillars of economic, environmental, and social factors (Palazzo & Vollero, 2021; Purvis et al., 2019), therefore I conclude that when addressing improvement of sustainability issues, one needs to take into consideration each of these aspects. In my research, I am interested in finding out how BCT, when applied in agri-food supply settings, can demonstrate the improvement of each of these factors.

Taking into account that the UN (2015) brought up the need to call all countries and stakeholders to act in collaborative partnership towards sustainable development and identified 'partnership' as a part of the Agenda for Sustainable Development Goals (UN, 2015), and by noticing other scholars talking about the cooperation of companies in the supply chain to achieve sustainability (Seuring & Müller 2008; Shingh et al., 2020), I identify collaboration between supply chain members as an important factor contributing to this concept.

That thought led me to recognize the agri-food supply chain as a proper environment for bringing aspects of effortless collaboration and partnership between stakeholders, and, in the following parts, I am going to investigate how BCT can be implemented for that purpose, at same time contributing to this aspect of sustainability.

With the use of data presented in the literature review part, I was able to identify: Sustainability Areas for Improvement in Agri-Food Supply Chain; Food Safety (Issues) in Agri-Food Supply Chain; Sustainability Areas for Improvement in Agri-Food Sector. In the following section, each of them is presented in a table as opposed to the effect of BCT on each of these 3 sustainability matters.

4.3. Blockchain for Sustainability in Agri-Food Supply Chain

The table represents summarized data extracted from the literature part on Sustainability Areas for Improvement in Agri-Food Supply Chain as opposed to Blockchain Effect on Sustainability in Agri-Food Supply Chain**.**

SUSTAINABILITY AREAS for IMPROVEMENT in AGRI-FOOD SUPPLY CHAIN	BCT EFFECT on SUSTAINABILITY in AGRI-FOOD SUPPLY CHAIN
• **food waste** (Sodamin et al., 2022) • **food adulteration** (Bagwasi & Raja, 2020) • **food safety issues** (Mukherjee et al., 2022) • **lack of openness in the supply chain** (Bagwasi & Raja, 2020) • **transparency and efficiency** (Tripoli & Schmidhuber, 2018) • **complicated and risky transactions** (Tripoli & Schmidhuber, 2018)	• **improved traceability and transparency** (Leduc et al., 2021; Feng et al.) • **improved farm-to-market flow** (Lakkakula et al., 2020) • **improved tracking of goods, inventory, and ownership throughout the whole supply chain** (Bhat et al., 2022) • **secure transactions** (Kaur, 2019) • **lower negative social and environmental impact** (Sodamin et al., 2022) • **shorter supply chain** (Wünsche & Fernqvist, 2022) • **verification of working conditions** (Wünsche & Fernqvist, 2022).

• **a low level of automation, lack of industrialization**, (Mukherjee et al., 2022) • **inconsistent and fragmented information** (Mukherjee et al., 2022) • **delayed payments, high transaction costs** (Mukherjee et al., 2022 • **presence of many intermediaries** (Tripoli & Schmidhuber, 2018) • **lack of trust among stakeholders** (Motta et al., 2020) • **low information transparency** (Motta et al., 2020)	• **improving farmer's position in the chain** (Wünsche & Fernqvist, 2022) • **trust among stakeholders** (Motta et al., 2020) • **lower transaction costs** (Mukherjee et al., 2022) • **fraud prevention** (Sodamin et al., 2022) • **food adulteration prevention** (Sodamin et al., 2022) • **more efficient supply chain**. (Sodamin et al., 2022) • **monitoring of sustainable practices** (Tiscini et al., 2020)

Table 2

The table shows that for the majority of sustainability areas for improvement in the agri-food supply chain, blockchain technology demonstrates a solution or a probable improvement. For example, the transparent nature of BCT may phase out the lack of trust among stakeholders, and secure transactions and a shorter supply chain may eliminate the presence of many intermediaries.

In the following part of the analysis, for a better overview of the matter, some of the aspects demonstrated in the table will be presented in simplified graphic models and hypothetical applications of blockchain technology in a product journey through the agri-food supply chain.

This part of the analysis mostly refers to BCT's influence on transactions, exchange of goods, preventing adulteration and waste of food products, overall supply chain management and efficiency, and farm-to-market flow.

a. Tagging and Registering of Goods

First and foremost, the transparency and traceability features of BCT need to be acknowledged as the most likely to make the agri-food supply chain transparent for all members of the food supply chain, from input suppliers to the end consumer, at every stage of the product journey along the supply chain.

As mentioned by Munir et al. (2022), blockchain is simply a digital database for tracking records of all the transactions of the supply chain. All the participants, who have no particular trust in each other, can collaborate without a need to rely on a trusted third party and they can access and check the ledger at any time (Ganne, 2018).

The immutability of blockchain makes alteration of recorded data not probable and a timestamp allows any supply chain member (who is a participant of the blockchain) to trace back the transaction and verify its details. That allows participants of a supply chain to trust each other while performing transactions and collaborate in the farm-to-market flow of goods without a need for an intermediary.

The graph below displays the food flow from input suppliers to the end consumer. Transparency and immutability of BCT enable facilitating tagging and registering the movement of food in the agri-food supply chain as a form of supply chain mapping providing all the information about food products and correlated transactions performed along the product journey.

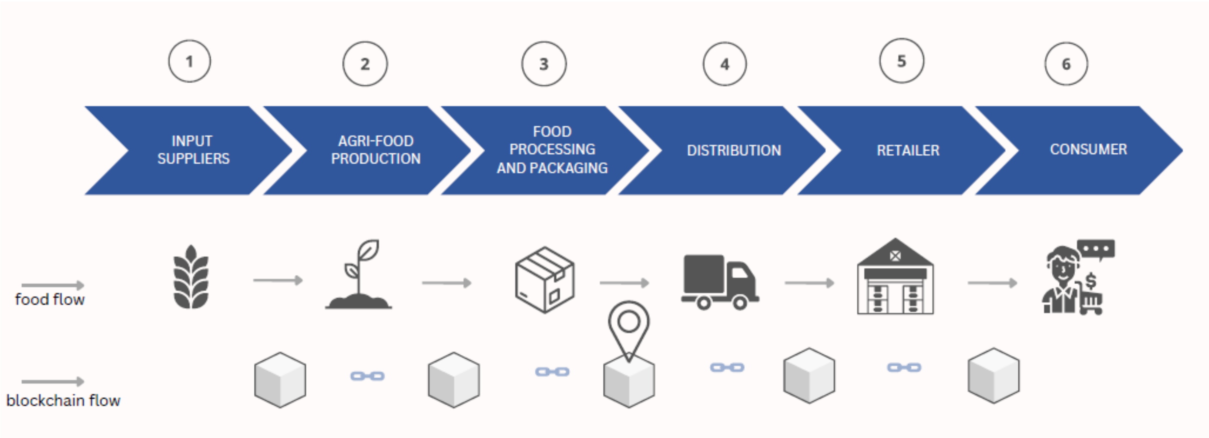

Figure 14

(Own creation, adapted from: Kamilaris et al., 2019)

b. Asset Registry

BCT would serve as a form of asset registry (Swan, 2015) along the supply chain for every member of an agri-food supply chain, providing them with all validated details about performed transactions. Physical items would be transferred to a smart asset stored on a blockchain, enabling its identification and authentication in exchange, inventory, and food label verification.

Figure 15

(own creation, based on Balaji, 2019)

c. Asset Specifications

When a food product is transferred to a smart asset, information about a farm origin, production method, batch number, processing technology, shipping details and storing temperatures would be digitally connected to a physical food product and all the information would be recorded on a blockchain at every step of the product journey throughout the supply chain (Galvez et al., 2018).

Figure 16

(own creation)

d. Smart Contracts

Blockchain technology enabled functioning of **smart contracts,** which:

- digitize paperwork, contain consistency of transactions (Wee Kwan & Sundarakani, 2021)
- acquire external information and automatically execute the orders agreed by the stakeholders (Ndiaye & Konate, 2021)
- are decentralized (Motta et al.2020)
- are self-executing, track transactions in real time, reduce paperwork and errors in the documents (Chang et al., 2020)
- are difficult to modify because their records are linked through hashes and they are encrypted and stored in a blockchain (Chang et al., 2020)

All of the smart contract features are applicable to be deployed in agri-food supply chain.

BCT would serve as oracle between supply chain members to test whether received goods meet particular contract requirements agreed upon in the sales contract (Lakkakula et al., 2020).

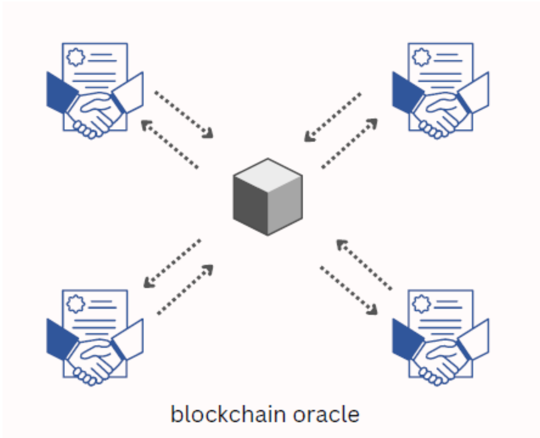

Figure 17

Simplified graphic of blockchain oracle. (Own creation, based on Al Breiki et al., 2020)

The simplified graph below depicts what happens when pre-defined conditions of a blockchain does not comply with the conditions found in a smart contract in the event of transaction initiation. Before a transaction between supply chain members is executed, blockchain checks whether provided conditions of a transaction comply with pre-defined conditions of the smart contract.

When the conditions are not met - the transaction is rejected.

When the conditions are met and consensus is reached - smart contract between parties is executed and a new block is added to the chain.

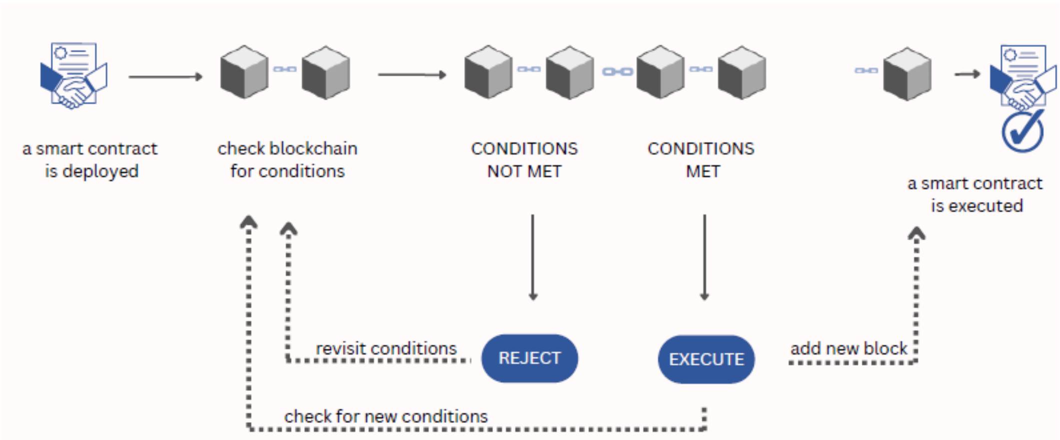

Figure 18

(Own creation, based on Jabbar et al., 2020)

There is a connection between the enforcement of transactions based on smart contracts in the agri-food supply chain and the possible improvement of sustainable practices performed. When pre-defined conditions are set to comply with particular sustainability norms - in a case when a party does not comply

with such conditions – the transaction will not be executed. Equally, specific sustainability clauses can be set in many settings of a contractual relationship between agri-food supply chain members.
Such a solution can be applied to sustainable and environmentally friendly transportation of goods and Munir et al. (2022) imply that blockchain-based contracts can develop and enhance the relationship among all the participants in a network of a supply chain.

Smart contracts are self-executing, they track transactions in real-time and they reduce paperwork and errors in the documents (Chang et al., 2020). That means that their deployment would address many issues identified as 'Sustainability Areas for Improvement in Agri-Food Supply Chain', such as complicated and risky transactions, low level of automation, delayed payments, or presence of many intermediaries and they would contribute to the more efficient and quicker flow of goods in the agri-food supply chain.

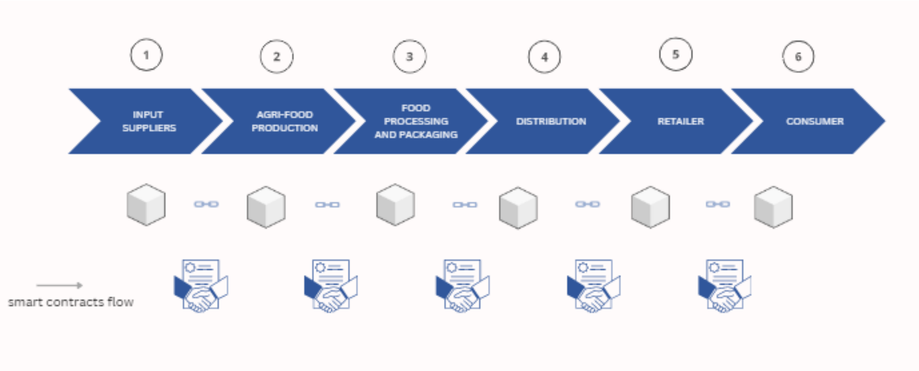

Figure 19

(Own creation, based on Kamilaris et al., 2019)

4.4. Blockchain for Food Safety in the Agri-Food Supply Chain

Food safety is a big part of sustainability issues in the agri-food supply chain, therefore a separate sub-chapter was created to elaborate on this matter.

Likewise, in the previous section, the data presented below is summarized from the literature review, including Food Safety Issues in the Agri-Food Supply Chain and the effect of BCT application in this context.

FOOD SAFETY (issues)	BCT for FOOD SAFETY
• **food contamination** (Martino et al., 2020) • **no compliance of foods with their label description** (Galvez et al., 2018) • **unsafe food products** (Martino et al., 2020) • **food falsification** (Galvez et al., 2018).	• **assessment of availability and originality of an agricultural commodity** (Sivianes & Bordons, 2021) • **providing details about quality and sustainability of the product** (Galvez et al., 2018) • **information about food products during transportation and storage** (Wünsche & Fernqvist, 2022)

	• **individualized perishability dates** (Wünsche & Fernqvist, 2022) • **risk prevention** (Okorie & Russell, 2021). • **sustainable by-product management** (Okorie & Russell, 2021) • **food spoilage and contamination reduction** (Lakkakula et al., 2020) • **food waste and foodborne diseases prevention** Wünsche & Fernqvist, 2022) • **quick microbiological analysis** (Kennedy et al., 2020). • **food labeling** (Alobid et al., 2022)

Table 3

The table above displays that BCT presents many possible solutions to food safety issues.
This section mostly refers to BCT's use for the external traceability of food and analyzes how BCT can improve food safety and food traceability through the agri-food supply chain. For this reason, the simplified graphic models will be applied in speculative circumstances.

a. Food Contamination

Contamination of food products is dangerous to the food supply (Martino et al., 2020). A solution identified by scholars to the majority of issues of food safety is achieving traceability. Traceability regulations demand from food businesses to be within the control of tracking food back and forward within a food supply chain (Ababouch, 2007).

To prevent food spoilage, BCT can benefit from connecting to IoT devices (source) sensing and controlling conditions of the products, such as temperature, humidity, etc. These sensing devices would provide data from their sensors to the oracle, which then would code and record information on a blockchain.

Entities involved in the flow of food through the product journey (farmers, transformers, distributors, retailers) would be connected to these IoT devices and they would be able to control the condition of produced, stored, and distributed food products along all the activities through the chain.

Blockchain would execute periodical self-checks for violation, checking whether the parameters coming from the devices comply with cryptographic pre-defined conditions of blockchain and smart contracts. When conditions are not met, an event for violation is triggered informing participants in the network. All participants of the network can access this data on a blockchain to check the records. That would prevent food spoilage along the food supply chain, at the same time limiting food waste.

Consequently, the same method would be used to verify whether the external conditions coming from the products at the port of exchange of goods comply with pre-defined conditions like desired storing temperature of a product. The conditions can be set according to the food safety rules and frameworks, which every actor in the chain needs to obey.

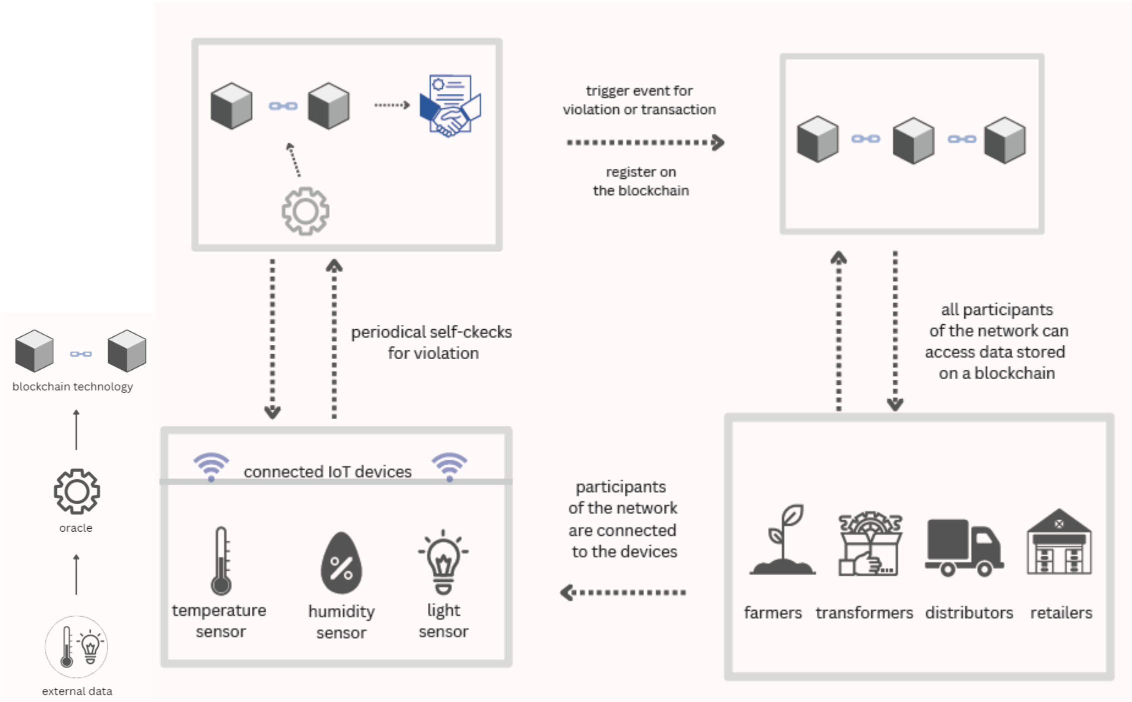

Figure 20

(Own creation, based on Pranto et al., 2021)

The graph below presents how BCT, in case of food contamination, enables quick and easy identification of the exact contaminated product position in the supply chain. Once contaminated produce is identified, blockchain will notify all the participants of the supply chain about the issue, preventing the further spread of a product along the chain, and, at the same time, trace back the origin of the contamination. This way, other food products coming from the same source can be immediately removed from the food supply chain. In turn, the outbreaks of foodborne diseases and food contaminations in the agri-food supply chain would be limited, preventing a final customer from food poisoning.

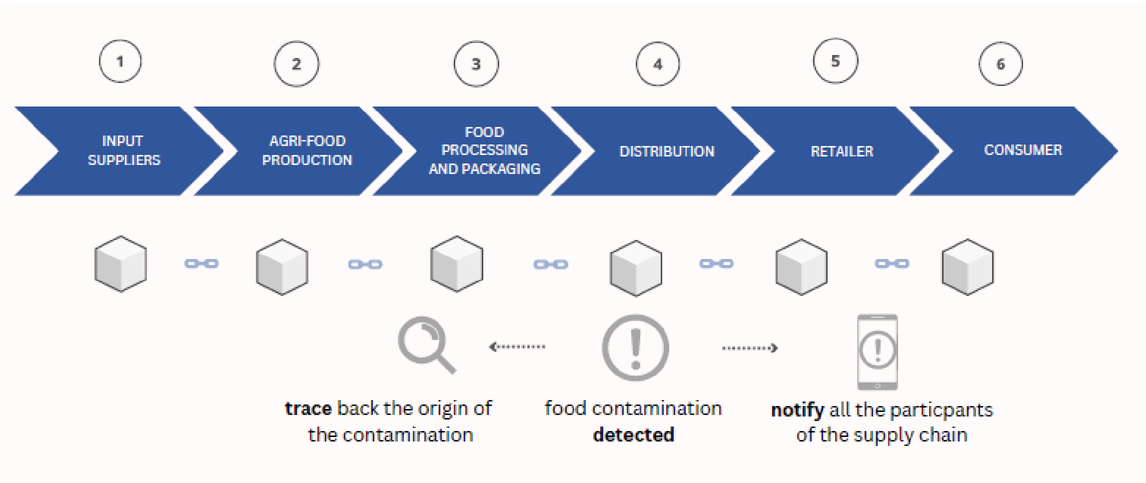

Figure 21

(Own creation, adapted from Kamilaris et al., 2019)

4.5. Blockchain for Sustainability in the Agri-Food Sector

Having been performing a literature review to address the problem formulation concerned with the improvement of sustainability matters along the agri-food supply chain, I recognized the need to bring awareness to blockchain application towards sustainability issues in the agri-food sector specifically.

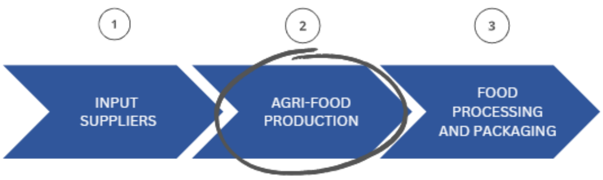

Figure 22

By following the premise of Iitsuka et al. (2019) indicating that to achieve an optimization of the food supply chain, agriculture needs to be revitalized, this study is focused on analyzing how BCT application, specifically, in the agri-food sector can contribute to the sustainable performance of the whole agri-food supply chain.

At this point, it is worth mentioning that this research does not focus on all the possible use of BCT in farming (which is an extensive topic), but on its deployment towards a sustainable agri-food sector as a part of a sustainable supply chain, where food is produced.

Another reason why there is significant attention put on the agri-food sector (and dedicating it a whole research question) is that many sustainability concerns are related to food production. As mentioned by Kaur (2019), to prevent food waste and ensure food availability, sustainable agriculture practices from farms to end consumers are needed and many sustainability issues are related to food production.

Moreover, to face climate change sustainability in the agricultural production system needs to be addressed (EC, 2020).

Referring to the statements above, I assume that to attain sustainability along the whole agri-food supply chain, actions towards sustainable development should have their root at the beginning of the chain, namely in farming and agri-food production. That is why, I decided to research how BCT can improve sustainability practices in the agri-food sector distinctly, taking into account farmers and agri-food production. I believe that without addressing sustainability matters at the starting point of the supply chain, further actions toward that goal might be counterintuitive or even counterproductive.

As done previously, the Sustainability Areas for Improvement in the Agri-Food Sector will be displayed next to essential data gathered for Blockchain Effect on Sustainability in the Agri-Food Sector. Next, they will be presented with the use of simplified graphic models.

SUSTAINABILITY AREAS for IMPROVEMENT in AGRI-FOOD SECTOR	BCT EFFECT on SUSTAINABILITY in AGRI-FOOD SECTOR
• **food waste prevention** (Kaur, 2019) • **ensuring food availability** (Kaur, 2019) • **production efficiency** (EC, 2020). • **traceability, security, and immutability of information** (Mercuri et al., 2021) • **reducing transaction costs** (Mercuri et al., 2021)	• **farmers' access to agricultural services** (Raboaca et al., 2020) • **improved effectiveness and operational productivity in agriculture** (Widi Widayat & Köppen 2021) • **use of personal and industrial data in production operations without invading personal privacy or trade secrets** (Yano et al., 2020) • **improved management and reduction of agricultural waste** (Kaur, 2019) • **the development of an internal economy** s Raboaca et al. (2020 • **improved working environment and employment** (Raboaca et al. 2020) • **intelligent market for soon-to-expire food**, (Wünsche & Fernqvist, 2022) • **no payment delays** (Alobid et al., 2022) • **intermediaries reduction** (Alobid et al., 2022) • **better prices and payment options for farmers** (Bagwasi & Raja, 2020) • **higher farmer's sales** (Li et al., 2020) • **farmers associations creation** (Raboaca et al. 2020)

Table 4

The table shows that the majority of BCT effects in the agri-food sector can be seen as beneficial for farmers, their internal economy, and their communities.

In the following section, visual examples of how BCT can be deployed in the agri-food sector will be presented. Point "a." analyzes BCT implementation for the internal traceability of food products, which in this case relates directly to agri-food production (contrary to the Food Safety section, which was mostly related to internal traceability). Points "b." and "c." discuss how this technology may contribute to farmers and their communities.

a. Intelligent Agriculture

Measurement of temperature, PH, acidity, and moisture of agricultural soil leads to improved effectiveness and operational productivity in agriculture (Widi Widayat & Köppen, 2021) and a sustainable food future takes into account food quality and security, soil and water management, drought, heat, and flooding. Consequently, agri-food businesses strive to measure production parameters, such as water use, soil enzymes, and pesticides, to enhance sustainability (Wünsche & Fernqvist, 2022).

In smart agriculture proposed by Shyamala Devi et al. (2019), components of blockchain nodes are sensing many external factors such as pollution, PH, or moisture, to name a few.

Correspondingly to the model presented in the previous section, in the agri-food sector, blockchain would be connected to the IoT sensors controlling the use of pesticides, energy usage, pollution, PH, biodiversity index, etc., and enable periodical self-checks of the sensors. In the event of a violation of pre-defined parameters for every sensor connected to an oracle, the technology would send a notification to participants of the network, informing them about the event of a violation.

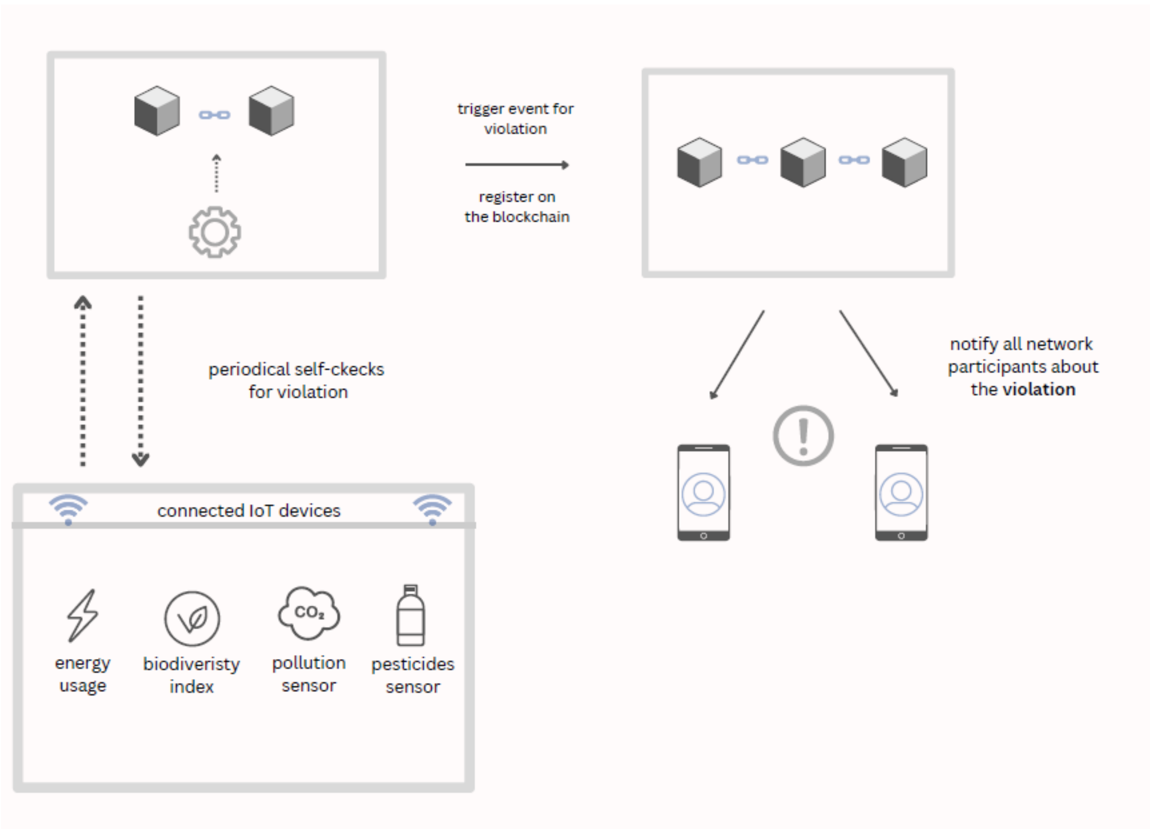

Figure 23

(Own creation, based on Pranto et al., 2021)

Apart from monitoring and controlling the use of pesticides or PH of the agricultural soil, actors in the agri-food sector would be able to monitor and control greenhouse gas emissions, or energy usage. The algorithms of blockchain would be able to check and verify whether the levels of emissions comply with pre-determined conditions set accordingly to the sustainable norms. In the event of the violation of a condition, all participants of the network would be notified. That way, harmful to the environment and society malpractices would be identified and limited while effectiveness and operational productivity in the agri-food sector improved.

b. Intelligent Sales

Another way of BCT deployment in the agri-food sector is the facilitation of intelligent sales and effortless transactions between food producers and other members of the chain with the use of smart contracts (figure 24)

BCT would open doors for an intelligent market for soon-to-expire food, where wholesalers would sell it to retailers at a lower price, under the condition that they could sell it within a time limit (Wünsche & Fernqvist, 2022). Furthermore, Kaur (2019) proposed the use of smart contracts for farmers to sell their produce before harvest on digital platforms (figure 25)

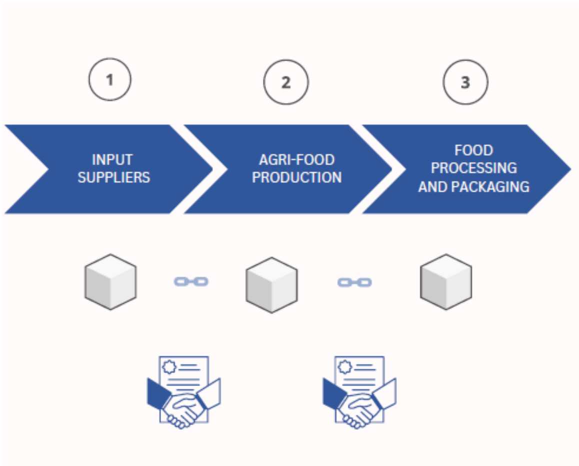

Figure 24
(own creation)

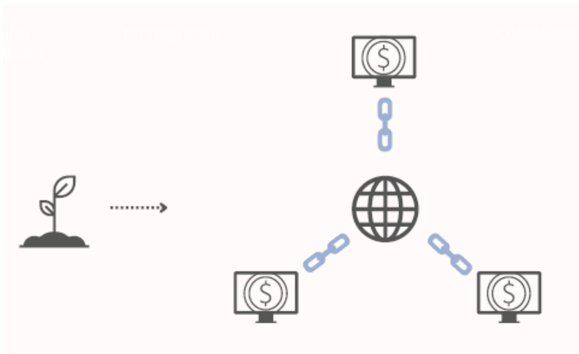

Figure 25
(own creation)

Both solutions are perceived as a positive impact on sustainability. They would prevent food waste, hinder wasting of resources and contribute to the development of farmers' internal economy.

c. Global Database for Farmers

With the use of BCT, farmers would be connected to a global blockchain network with a digitally assigned node account based on each of their roles, resulting in effortless transactions within the network (Widi Widayat & Köppen 2021). This globally distributed database would create a space for farmers to prove the quality and originality of food, as well as display any food certifications. That would result in transparency and trust between stakeholders. (figure 26)

BCT would enable farmers to be a part of farming associations in a globally diversified network providing information on water floods, scarcity, the most adaptable crop seeds, animal breeds, guidelines on how to limit gas emissions, and how to contribute to socioeconomic practices (Van Wassenaer et al., 2021). The features of BCT would allow farmers to access desired reliable information at any time. That could enhance their competence and make them more united and cooperative. (figure 27)

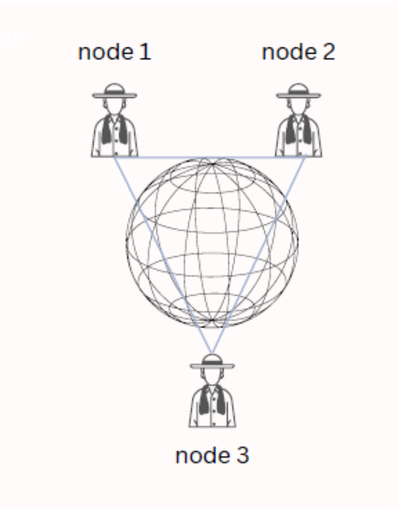

Figure 26

(own creation)

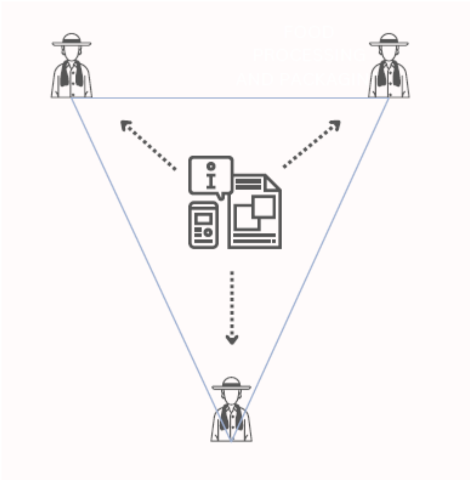

Figure 27

(own creation)

4.7. Global Perspective

This section discusses a global view of this research.

Agri-food supply chains are changing into globally interconnected systems that are made of complex relationships (Naik & Suresh, 2018), meanwhile, food security has become a global issue, and policymakers worldwide are discussing ways to improvement of this matter. Furthermore, there is a lack of transparency in global supply chains, which results in many inefficiencies, and negative social and environmental effects (Mercuri et al., 2021).

Food waste has a significant negative effect on sustainability as about one-third of all food produced is lost or wasted globally, meaning that the resources of the planet are misused (Wünsche & Fernqvist, 2022).

The problems with food adulteration, food contamination, and spoilage or inefficient supply chains should be addressed from a global perspective, involving regulatory bodies and stakeholders of global food supply chains.

All of these factors imply that to address sustainability issues in the agri-food supply chain, the global outlook on these matters needs to be considered, as focusing on achieving sustainability within the agri-food sector only might not be enough. On the other hand, based on the conclusion from the analysis section on the agri-food sector, it should be noted that focus on sustainable farming and agri-food production shall not be neglected.

As mentioned by Rana (2021), BCT could contribute to the improvement of global supply chains, especially in the agri-food sector and it could positively contribute to minimizing social and environmental impacts.

Each of the aspects of BCT's positive effect on sustainability matters which have been previously analyzed in this chapter could consequently be applied in global settings too.

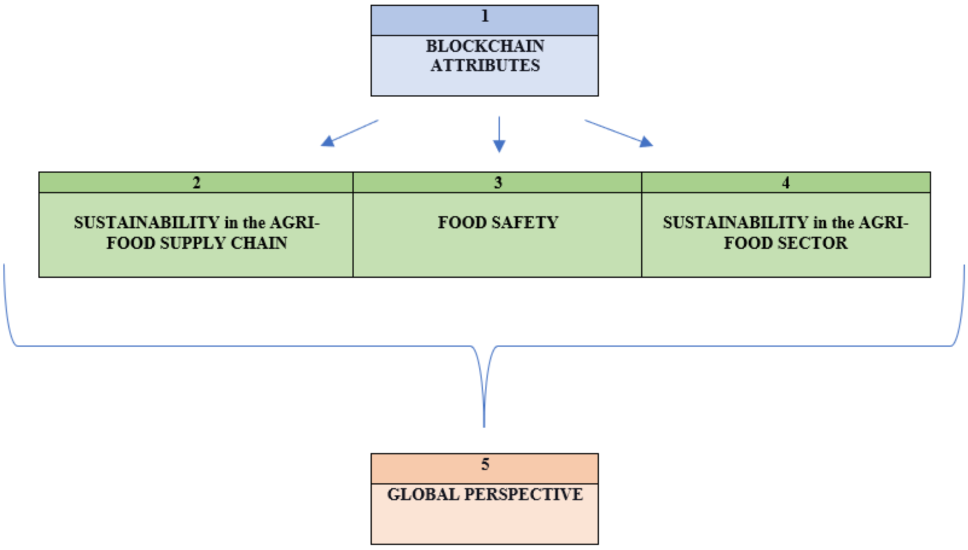

Figure 28

For example, tagging and registering of goods on the blockchain would play a part in an international and cross-sectoral exchange of goods (Dorfleitner et al., 2021) or BCT could serve as an oracle to test if the goods meet pre-defined contract requirements at the port of entry (Lakkakula et al., 2020).

All in all, the global aspect of this research is of high significance. Agri-food supply chains are becoming globally interconnected, meaning that any improvement in their sustainable performance is likely to have a positive global impact on sustainable development.

4.8. Barriers to Blockchain Implementation in Agri-Food Supply Chain and Agri-Food Sector

A reviewed literature discussed barriers to BCT implementation, mostly, in the agri-food sector or a supply chain, generally, with no particular implications for the agri-food supply chain, especially. However, I believe they are of high importance to the outcome of this research. Thus, for the aim of critical and comprehensive analysis, they need to be addressed attentively.

Similarly to other parts of the analysis, the identified barriers to BCT implementation in the agri-food supply chain and agri-food sector are summarized and displayed next to the points identified in the previous sections of this chapter.

It can be noticed that this table also represents the analysis of the four research questions.

BCT EFFECT on SUSTAINABILITY in AGRI-FOOD SUPPLY CHAIN	**BARRIERS to BCT IMPLEMENTATION in AGRI-FOOD SC & SECTOR**
• **secure transactions** (Kaur, 2019) • **trust among stakeholders** (Motta et al., 2020) • **monitoring of sustainable practices** (Tiscini et al., 2020) • **fraud prevention** (Sodamin et al., 2022) • **lower negative social and environmental impact** (Sodamin et al., 2022) • **lower transaction costs** (Mukherjee et al., 2022) • **more efficient supply chain**. (Sodamin et al., 2022) • **improving farmer's position in the chain** (Wünsche & Fernqvist, 2022) • **shorter supply chain** (Wünsche & Fernqvist, 2022) • **verification of working conditions** (Wünsche & Fernqvist, 2022) • **improved traceability and transparency** (Leduc et al., 2021; Feng et al.). • **improved farm-to-market flow** (Lakkakula et al., 2020) • **improved tracking of goods, inventory, and ownership** (Bhat et al., 2022) • **food adulteration prevention** (Sodamin et al., 2022) BCT for FOOD SAFETY in AGRI-FOOD SUPPLY CHAIN • **assessment of availability and originality of an agricultural commodity** (Sivianes & Bordons, 2021) • **providing details about quality and sustainability of the product** (Galvez et al., 2018) • **food labeling** (Alobid et al., 2022) • **information about food products during transportation and storage** (Wünsche & Fernqvist, 2022). • **individualized perishability dates** (Wünsche & Fernqvist, 2022). • **risk prevention** (Okorie & Russell, 2021) • **sustainable by-product management** (Okorie & Russell, 2021) • **food spoilage and contamination reduction** (Lakkakula et al., 2020 • **food waste and foodborne diseases prevention** Wünsche & Fernqvist, 2022) • **quick microbiological analysis** (Kennedy et al., 2020) BCT EFFECT on SUSTAINABILITY in AGRI-FOOD SECTOR • **use of personal and industrial data in production operations without invading personal privacy or trade secrets** (Yano et al., 2020) • **intermediaries reduction** (Alobid et al., 2022) • **improved working environment and employment** (Raboaca et al. 2020) • **development of farmer's internal economy** (Raboaca et al. (2020 • **farmers associations creation** (Raboaca et al., 2020) • **farmers' access to agricultural services** (Raboaca et al., 2020) • **improved effectiveness and operational productivity in agriculture** (Widi Widayat & Köppen 2021) • **improved management and reduction of agricultural waste** (Kaur, 2019) • **intelligent market for soon-to-expire food**, (Wünsche & Fernqvist, 2022) • **no delays in payments** (Alobid et al., 2022). • **better prices and payment options for farmers** (Bagwasi & Raja, 2020) • **higher farmer's sales** (Li et al., 2020)	• **legal matters issues** (Jefford, 2021) • **lack of regulations for data sharing** (Wünsche & Fernqvist, 2022) • **issues regarding regulations, standards, governance** (Palazzo & Vollero, 2021; Galvez et al., 2018) • **privacy leakage** (Rana et al., 2021) • **high energy consumption** (Dorfleitner et al., 2021; Biswas et al., 2022; Parmentola et al., 2022) • **high risks of technical, managerial and ethical issues** (Parmentola et al., 2022) • **digital literacy issues** (Esteso et al., 2021) • **limited transaction capacity and higher processing time** (Dorfleitner et al., 2021) • **a need for structural and organizational changes** (Wünsche & Fernqvist 2022) • **widespread acceptance, education, training and understanding of smart technology is required** (Luo et al., 2022) • **a need for policy support and technology promotion** (Luo et al., 2022) • **high development costs** (Okorie & Russell 2021; Rana et al., 2021; Parmentola et al., 2022) • **a need for infrastructures** (Esteso et al., 2021) • **issues related to storage, scalability, capacity** (Okorie & Russell 2021) • **lack of expertise** (Okorie & Russell 2021) • **connectivity problems** (Rana et al., 2021) • **low technical and economic resources in developing countries** (Luo et al., 2022) • **lack of awareness related to implementation of new technologies** (Ancín et al., 2022) • **transition needs much know-how and maintenance of technology** (Mukherjee et al., 2022). • **immaturity phase** (Palazzo & Vollero, 2021; Okorie & Russell, 2021; Li et al., 2020) • **a unique value added is questioned** (Loklindt et al., 2018) • **BCT should be able to inter-operate with other blockchains and other IT systems** (Dorfleitner et al., 2021) • **accumulation and/or blending of multi-sourced materials** (Okorie & Russell, 2021) • **only few practical applications are identified** (Antonucci et al., 2019)

Table 5

As displayed above, there are plenty of barriers to BCT implementation in agriculture, and they have severe implications. The majority of them can be applied as contradictory to an allegedly positive impact of BCT implementation. Categorizing and assigning them to each of the three cases is not easy, as all of the barriers seem to apply to each of them.

However, for the purpose of finding a path, I marked contradictory statements with the same color in the “barriers part” and in the three of the “BCT effect” part. That served to distinguish discrepancies between promising aspects of BCT applied in one context (left side of the table) and negating statements (right side of the table) to the same factor. For example, fraud prevention is called into question while facing the aspect of lack of regulations for data sharing, legal matters, governance, or privacy leakage. Or high energy consumption of BCT is contradictory to an assumingly lower environmental impact, as well as lower transaction costs may not be of significance while facing high deployment cost and a need for structural and organizational changes.

Although the table does not evince a positive outcome of BCT application to the improvement of sustainability matters in the light of such compelling barriers to implementation of this technology, there still are some promising aspects that can be identified. They will be discussed in the next section.

4.9. Conceptual Framework

The purpose of this section is to represent the relationship between the variables identified in the research questions and which, consequently, were the subjects of the analysis. The conceptual framework will serve as a guide to recognizing the findings of this research.

BLOCKCHAIN ATTRIBUTES

SUSTAINABILITY in AGRI-FOOD SUPPLY CHAIN			
• secure transactions • trust among stakeholders • fraud prevention	• lower negative social and environmental impact • lower transaction costs • more efficient supply chain	• shorter supply chain • improved farm-to-market flow • monitoring of sustainable practices • improved working environment and employment	• improved traceability • improved tracking of goods, inventory, and ownership • food adulteration prevention

• legal matters issues • lack of regulations for data sharing and privacy leakage • issues regarding regulations, standards, governance	• high energy consumption • high development costs • high risks of technical, managerial and ethical issues • limited transaction capacity and higher processing time • issues related to storage, scalability, capacity • transition needs much know-how and maintenance of technology	• a need for structural and organizational changes • widespread acceptance, education, training and understanding of smart technology is required • a need for policy support and technology promotion • a need for infrastructures • a need for inter-operation with other blockchains and other IT systems • connectivity problems • low technical and economic resources in developing countries • lack of awareness related to implementation of new technologies • digital literacy issues
BARRIERS to BLOCKCHAIN IMPLEMENTATION		

• assessment of availability and originality of an agricultural commodity • providing details about quality and sustainability of the product • food labeling • information about food products during transportation and storage	• individualized perishability dates • sustainable by-product management • food spoilage and contamination reduction • food waste and foodborne diseases prevention • quick microbiological analysis
FOOD SAFETY	

BLOCKCHAIN ATTRIBUTES

BLOCKCHAIN ATTRIBUTES

SUSTAINABILITY in AGRI-FOOD SECTOR

- intermediaries reduction
- improved effectiveness and operational productivity
- improving farmer's position in the chain
- improved working environment and employment
- no delays in payments
- better prices and payment options for farmers

- development of farmer's internal economy
- farmers associations creation
- farmers' access to agricultural services
- use of personal and industrial data in production operations without invading personal privacy or trade secrets
- intelligent market for soon-to-expire food
- higher farmer's sales
- improved management and reduction of agricultural waste

- a need for structural and organizational changes
- a need for policy support and technology promotion
- high development costs
- a need for infrastructures
- issues related to storage, scalability, capacity

- lack of expertise
- connectivity problems
- low technical and economic resources in developing countries
- lack of awareness related to implementation of new technologies
- transition needs much know-how and maintenance of technology
- digital literacy issues
- a need for inter-operation with other blockchains and other IT systems
- widespread acceptance, education, training and understanding of smart technology is required

BARRIERS to BLOCKCHAIN IMPLEMENTATION

The green arrows show the blockchain effect on sustainability in the agri-food supply chain, food safety, and stainability in the agri-food sector. The blue (and yellow) arrows represent corresponding barriers hindering their performance. The yellow arrows point out which of the BCT's effects on sustainability areas are most likely to be reached.

The conceptual framework shows that a successful implementation of BCT in agri-food supply chain is questionable due to the big range of barriers to blockchain implementation. The most apparent of them are listed in the table below:

THE MOST APPARENT BARRIERS to BCT IMPLEMENTATION
• a need for infrastructures
• a need for inter-operation with other blockchains and other IT systems
• a need for policy support and technology promotion
• a need for structural and organizational changes
• connectivity problems
• digital literacy issues
• high development costs
• issues regarding regulations, standards, governance
• issues related to storage, scalability, capacity
• lack of awareness related to implementation of new technologies
• lack of expertise
• lack of regulations for data sharing and privacy leakage
• legal matters issues
• low technical and economic resources in developing countries
• transition needs much know-how and maintenance of technology
• widespread acceptance, education, training and understanding of smart technology is required

Table 6

Nevertheless, there are some areas in which BCT is more likely to improve sustainability aspects in the agri-food supply chain. They are displayed in the table below:

THE MOST PROBABLE SUSTAINABILITY ASPECTS TO BE ACHIEVED
• food adulteration prevention
• food spoilage and contamination reduction
• food waste and foodborne diseases prevention
• improved traceability
• improved tracking of goods, inventory, and ownership
• individualized perishability dates
• quick microbiological analysis
• sustainable by-product management

Table 7

Identified above aspects are related to food safety concerns in the agri-food supply chain. Putting aside all the barriers, if BCT could be applied in any of the sectors along the agri-food supply chain, the promise for improvement might be spotted. Assuming that a particular agri-food sector can handle the barriers of connectivity problems, digital literacy issues, and lack of expertise, and would be given policy and governmental support for structural and organizational changes, the technology would have a chance for a successful deployment.

Referring to the "Blockchain for Sustainability in the Agri-Food Sector" part of the analysis, successful deployment of BCT in one of the sections of the agri-food SC might have beneficial results on the sustainability initiatives.

If BCT is deployed for internal traceability of agri-food production, then food adulteration, spoilage and contamination, food waste, and the outbreak of foodborne diseases would be reduced. That has a direct influence on food safety, which is a big factor in sustainable development.

5. Discussion

This section discusses what implications and recommendations this study provides and what further steps of expanding this research could involve. Also, the limitations encountered while developing this research study are discussed.

5.1. Practical Implications and Recommendations

Although the problem formulation of this research is not directly related to international business, it can provide some insights into this field, considering that the global dimension of agri-food supply chain management played an important part in this research. Moreover, sustainability matters are affecting the performance of businesses as stakeholders' expectations for sustainable development are rising. Furthermore, food safety, which is discussed in this paper, is becoming a global issue, and in light of current global issues, such as the food crisis, any way to improvement this issue is relevant.

The most apparent implications of this study are related to the barriers to blockchain implementation, which hinder the majority of promising effects of the deployment of this technology. The need for policy support, structural and organizational changes, regulations, standards, and governance regarding the implementation of new digital technologies is evident. Moreover, the legal issues concerned with the lack of regulations for data sharing and privacy leakage should also be addressed.

Another clear implication of this study is the need for cooperation between members of the food supply chain. Food safety is not an issue applied in agri-food settings only but it concerns all the entities concerned with the food supply chain. The importance of cooperation of the stakeholders is apparent even when the BCT does not evince any positive contribution to the food safety matter. The resources of the planet are wasted due to food waste and food adulteration, and on the other hand, there is a shortage of food. Therefore, it can be concluded that immediate cooperation of all policymakers for food safety is needed along with legal advice on how to overcome the barriers of new developments.

Furthermore, the research implies that even the most promising aspects of technological development cannot be implemented on a global scale, due to low technical and economic resources in developing countries and digital literacy issues. Thus, addressing these matters would be a significant attribution to sustainability from a global perspective.

5.2. Limitations

One of the most significant limitations during the development of this research was that the majority of publications selected for the literature review were not discussing the long-term effects of BCT implementation as the implementation of this technology is still in the immaturity phase. Hence, the implications, in the long run, are not known. Furthermore, the literature discussing blockchain's effect on sustainability matters or its application in agricultural settings was often speculative. That leads to the development of consequently speculative findings of this research.

Another important limitation was no sufficient information to support the discussion about the global perspective in relation to the problem formulation. That is, repeatedly, based on the immaturity of BCT development in these settings. Moreover, other technological enhancements in agriculture are also not highly developed, thus there is no wide range of possibilities to identify a unique value-added of BCT in these settings until progress in technological development takes place.

Lastly, the time frame dedicated to this project can also be perceived as a limitation of a kind. During the finishing stage of this research, more publications were available regarding this subject than in the final collection of sources applied in the literature review part. The reason is that BCT and its deployment in various settings is a trending topic for research. That leads to another limitation, namely which is rapidly changing information regarding the consequences of BCT deployment in various settings. Thus, it is easy to lose the track of the facts and it is challenging to assess the validity of publications and identify the current value offered by this technology.

Moreover, given more time, this study could have gained more technical dimension resulting in a more detailed analysis of the research questions with a more in-depth focus on the barriers to BCT implementation and possible ways to overcome them.

Lastly, the research design of this study was a limitation, as the results of the research are solely based on secondary data, and no new data was collected, which would most likely create a more critical outcome of the study.

5.3. Further Research

A research design for further investigation of this study would be multidisciplinary. Researchers from different fields could contribute to the common problem of BCT deployment in the agri-food supply chain and food safety settings by focusing on the area of their expertise. Multidisciplinary research is proposed because blockchain is a complex technology with many technological aspects to be understood and analyzed from a more technical point of view. Furthermore, there is plenty of legal matters that would need to be investigated in this field, as the lack of legal regulations for data sharing is apparent in the investigation of this research topic. Thus, for example, it is counterproductive to assess the influence of BCT on building trust among stakeholders not knowing what are the legal implications in this matter. Furthermore, future research should be empirical. The theoretical dimension of this study was a clear limitation to the new knowledge creation.

6. Conclusion

This section concludes the study by demonstrating the essence of this research. The research questions will be presented with explanation how they were addressed in this study and how they contributed to answering the problem of this research.

This study was designed to investigate the possible influence of BCT on the improvement of sustainability in the agri-food supply chain. The initial idea of the research was to investigate what promising aspects of BCT application for sustainability purposes in different settings would have while applied specifically in the agri-food supply chain. To close the research gap, the global dimension, and two other elements were added to the scope of investigation of this research, which was based on the main problem: *"How can blockchain technology improve sustainability in the agri-food supply chain from a global perspective?"* For a comprehensive interpretation of this problem and desire the contribution to the new knowledge creation, four research questions were developed.

The purpose of the research question is "*How can blockchain technology improve sustainability in the agri-food supply chain?"* was to identify the BCT effect on the agri-food supply chain at the bigger picture, discuss the nature of transactions between agri-food supply chain members and analyze a food product journey from farm to the end customer.

The research question "*How can blockchain technology improve food safety in the agri-food supply chain?"* aimed to provide a detailed viewpoint on food safety as a significant part of sustainability issues in the agri-food supply chain and application of BCT for this purpose.

"How can blockchain technology improve sustainability in the agri-food sector?" question was designed to investigate effect of BCT on sustainability matters, specifically in the agri-food sector, mostly focused on how the application of BCT in farming and agri-food production could contribute to the overall sustainability of the agri-food supply chain.

The answers to each of these questions were given in the analysis part of this research. However, they are purposely not included in the conclusion, because the fourth research question significantly changes their value and reliability.

The research question approaches the result of the study from another perspective, raising the question to "*What are the barriers to blockchain technology implementation in the agri-food supply chain and agri-food sector?"* identified weak points of BCT implementation in the agri-food supply chain and, at the same time, invalidated previous outcomes.

This research showed that there are many barriers to BCT implementation in agri-food supply chain settings and they outweigh many possible improvements in sustainability matters in agri-food supply chain and sector. These are a need for policy support and structural and organizational changes, digital literacy issues, high development costs, or issues regarding regulations, standards, and governance, as well as low technical and economic resources in developing countries.

Nonetheless, despite numerous barriers to BCT implementation, there are some areas in which BCT is more feasible to improve sustainability aspects in the agri-food supply chain. If any member of an agri-food supply chain would overcome the barriers of connectivity problems, digital literacy issues, and lack of expertise, and would be given policy and governmental support for structural and organizational changes, the technology would have a chance to have a desired positive outcome on the improvement of sustainability matters in the agri-food supply chain settings. This research exposes that the significance of BCT barriers is the lowest when applied to the internal traceability of agri-food production. Meaning, that the sustainability factors that are the most likely to be addressed with the application of BCT are food adulteration, spoilage and contamination, food waste, and the outbreak of foodborne diseases. That has a direct influence on food safety, which is a big factor in sustainable development

The food safety area can be recognized as the most feasible to overcome the barriers to BCT implementation, having a positive contribution to sustainability matters, given that the external regulatory bodies and policymakers would collaborate towards the same goal. Deployment of BCT seems to be the most promising for attaining food safety and traceability along the agri-food supply chain but policy guidance and governmental support is needed along with the cooperation of supply chain members.

Furthermore, the outcome of this research implies that even though BCT evinces a way to improve sustainability matters such as food safety throughout the agri-food supply chain while looking at the problem from a global perspective, low technical and economic resources in developing countries like digital literacy or connectivity problems are hindering the sustainable development. Thus, addressing these matters by regulatory bodies and providing support, new infrastructures creation, education and training for understanding digital technologies, and improving technical resources in developing countries would be a significant contribution to sustainability from a global perspective, and the BCT is only the trigger for a change.

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8. Appendix A.

	Name	Type	Year of Publication
1	Academy of Management Perspectives	Scientific Journal	2021
2	Advances in Intelligent Networking and Collaborative Systems: The 13th International Con	Book	2022
3	Advances in Production Management Systems. Production Management for the Factory o	Book	2019
4	Agricultural Systems	Scientific Journal	2022
5	Agriculture (Basel)	Scientific Journal	2022
6	AGRIS on-line Papers in Economics and Informatics	Scientific Journal	2022
7	AIMS Agriculture and Food	Scientific Journal	2021
8	arXiv preprint arXiv	Scholar Database	2018
9	Asian Journal of Economics, Business and Accounting	Scientific Journal	2020
10	Assessing the Environmental Impacts of Consumption and Production: Priority Products ar	Report	2010
11	Benchmarking: An International Journal,	Scientific Journal	2021
12	Blockchain and Applications: 3rd International Congress	Book	2021
13	Blockchain and Applications: 3rd International Congress	Book	2021
14	Blockchain and Applications: 3rd International Congress	Book	2021
15	Blockchain and Crypto Currency: Building a High Quality Marketplace for Crypt Data	Book	2020
16	Blockchain for business: how it works and creates value	Book	2021
17	Blockchain Research Institute-IBM Institute for Business	Report	2019
18	Blockchain: Blueprint for a New Economy	Book	2015
19	British Food Journal	Scientific Journal	2016
20	British Food Journal	Scientific Journal	2021
21	Business Strategy and the Environment	Academic Journal	2021
22	Business Strategy and the Environment	Academic Journal	2022
23	Business Strategy and the Environment	Academic Journal	2022
24	Business Strategy and the Environment	Scientific Journal	2022

25	Can Blockchain revolutionize international trade	Book	2018
26	Climate and Development	Academic Journal	2019
27	Cogent Economics & Finance	Open Access Journal	2019
28	Computers & Operations Research	Academic Journal	2018
29	Consensus-as-a-service: a brief report on the emergence of permissioned, distributed ledg	Report	2015
30	Decentralized Business Review	Business Review	2008
31	Deloitte	Report	2016
32	Earth System Governance	Scientific Journal	2021
33	Engineering, Technology & Applied Science Research	Scientific Journal	2019
34	Environmental Science & Technology	Scientific Journal	2022
35	European Central Bank	ECB Publication	2017
36	European Central Bank	ECB Publication	2017
37	European Commission	Regulation	2002
38	European Commission	Report	2020
39	European Journal of Operational Research	Scientific Journal	2022
40	FAO and WUR	Report	2021
41	FAO, International Centre for Trade and Sustainable Development.	Report	2018
42	Food and Agriculture Organization of the United Nations	FAO Publication	2023
43	Food and Agriculture Organization of the United Nations	FAO Publication	2023
44	Food safety engineering	Book	2020
45	Food safety engineering	Book	2020
46	Food Safety Engineering	Book	2020
47	Food Safety Engineering	Book	2020
48	Frontiers in Blockchain	Scientific Journal	2020
49	Frontiers in Energy Research	Scientific Journal	2022
50	Futures	Scientific Journal	2020
51	Global Food Security	Scientific Journal	2020
52	Global Trade Conference on Aquaculture	Report	2007
53	Harvard Business Review	Business Review	2017
54	IEEE Access	Scientific Journal	2020
55	IEEE Access	Scientific Journal	2019
56	IEEE Access	Scientific Journal	2019
57	IEEE Engineering Management Review	Scientific Journal	2019
58	IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Ir	Scientific Journal	2017
59	IIMB management review	Scientific Journal	2018
60	Information	Scientific Journal	2020
61	Innovative Product Design and Intelligent Manufacturing Systems	Book	2020
62	Integration of Information Flow for Greening Supply Chain Management	Book	2020
63	Integration of Information Flow for Greening Supply Chain Management	Book	2020
64	Integration of Information Flow for Greening Supply Chain Management	Book	2020
65	Intelligent Information Management	Scientific Journal	2017
66	International Conference on Dynamics in Logistics	Book	2018
67	International Conference on Emerging Technologies in Computer Engineering	Book	2019
68	International Conference on Exploring Services Science	Book	2017
69	International Journal of Advances Research	Scientific Journal	2020
70	International Journal of Production Research	Scientific Journal	2020
71	International Journal of Production Research	Scientific Journal	2019
72	International Journal of Production Research	Scientific Journal	2020

73	International Journal of Web and Grid Services	Scientific Journal	2018
74	J	Scientific Journal	2019
75	Journal of Agricultural Sciences	Scientific Journal	2021
76	Journal of Business Logistics	Scientific Journal	2001
77	Journal of Cleaner Product	Scientific Journal	2020
78	Journal of Cleaner Production	Scientific Journal	2022
79	Journal of cleaner production	Scientific Journal	2020
80	Journal of Cleaner Production	Scientific Journal	2020
81	Journal of Cleaner Production	Scientific Journal	2021
82	Journal of Cleaner Production	Scientific Journal	2008
83	Journal of Cleaner Production	Scientific Journal	2021
84	Journal of Global Operations and Strategic Sourcing	Scientific Journal	2021
85	Journal of Innovation Management	Scientific Journal	2019
86	Journal of the Science of Food and Agriculture	Scientific Journal	2019
87	Logistics	Scientific Journal	2018
88	Logistics	Scientific Journal	2018
89	Logistics	Scientific Journal	2022
90	Management Decision	Scientific Journal	2020
91	Mathematics	Scientific Journal	2020
92	MIS Quarterly Executive	Scientific Journal	2018
93	Operations Management Research	Scientific Journal	2022
94	Opportunities and challenges for private and consortium blockchains	Report	2016
95	PeerJ Computer Science	Scientific Journal	2021
96	Proceedings of the 3rd international conference on crowd science and engineering	Book	2018
97	Proceedings of the international conference on industrial engineering and operations man	Book	2019
98	Proceedings of the International Conference on Sustainable Design and Manufacturing	Book	2021
99	Renewable and Sustainable Energy Reviews	Scientific Journal	2021
100	Report of the World Summit on Sustainable Development, Johannesburg, South Africa	Report	2002
101	Research Handbook on Digital Transformations	Book	2016
102	Resources, Conservation and Recycling	Scientific Journal	2019
103	Review of International Business and Strategy	Scientific Journal	2020
104	Robotics and Computer-Integrated Manufacturing	Scientific Journal	2020
105	Routledge.	Scientific Journal	2018
106	Smart contracts	Intranet Document	1994
107	SSRN	Scientific Journal	2017
108	Strategic Direction	Scientific Journal	2021
109	Sustainability	Scientific Journal	2022
110	Sustainability	Scientific Journal	2022
111	Sustainability	Scientific Journal	2018
112	Sustainability	Scientific Journal	2022
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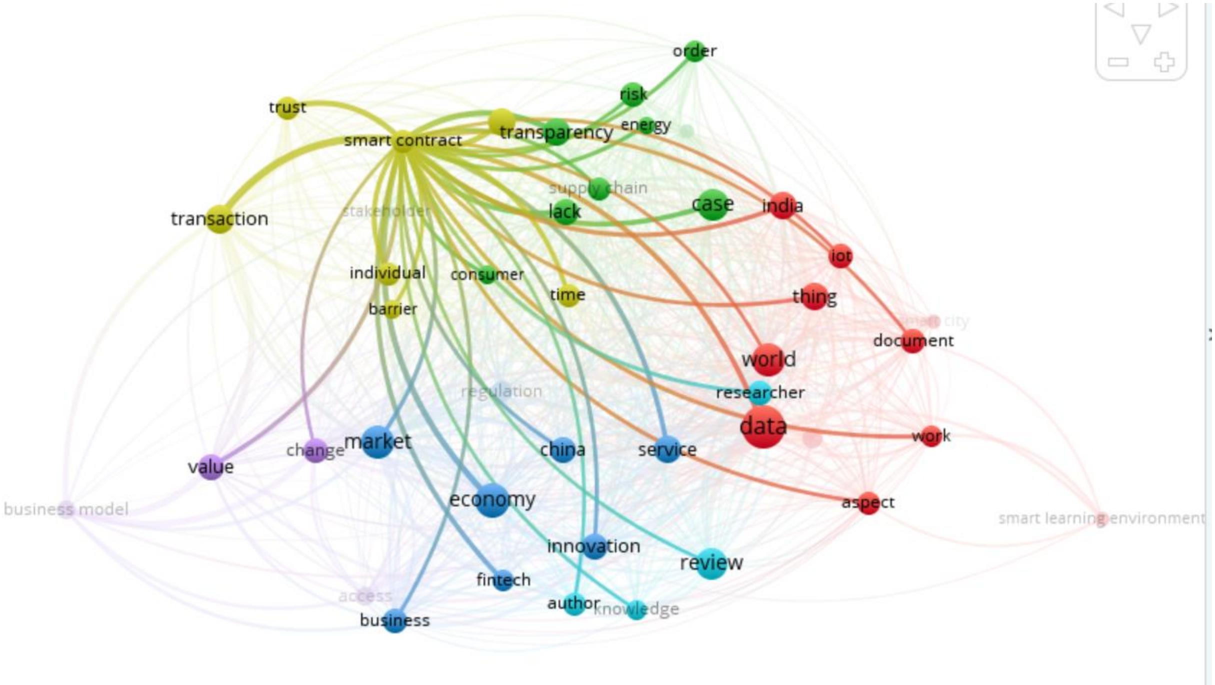
114	Sustainability	Scientific Journal	2021
115	Sustainability	Scientific Journal	2022
116	Sustainability Science	Scientific Journal	2019
117	Systems Engineering	Scientific Journal	2017
118	Technological Forecasting and Social Change	Scientific Journal	2020
119	Technological Forecasting and Social Change	Scientific Journal	2022
120	The journal of international social research	Scientific Journal	2009
121	The Journal of Private Enterprise	Scientific Journal	2020
122	The Romanian Economic Journal	Scientific Journal	2019
123	The School of Public Policy Publications	Scientific Journal	2019
124	TQM Journal	Scientific Journal	2021
125	Transforming our world: the 2030 Agenda for Sustainable Development.	Agenda	2015
126	Trends in analytical chemistry	Scientific Journal	2018
127	Trends in Food Science & Technology	Scientific Journal	2019
128	Trends in Food Science & Technology	Scientific Journal	2021
129	Trends in Food Science & Technology	Scientific Journal	2019
130	UNCITRAL 50th anniversary congress	Report	2017
131	WCO Research Paper	Journal	2018
132	World Economic Forum	Report	2018

9. Appendix B.



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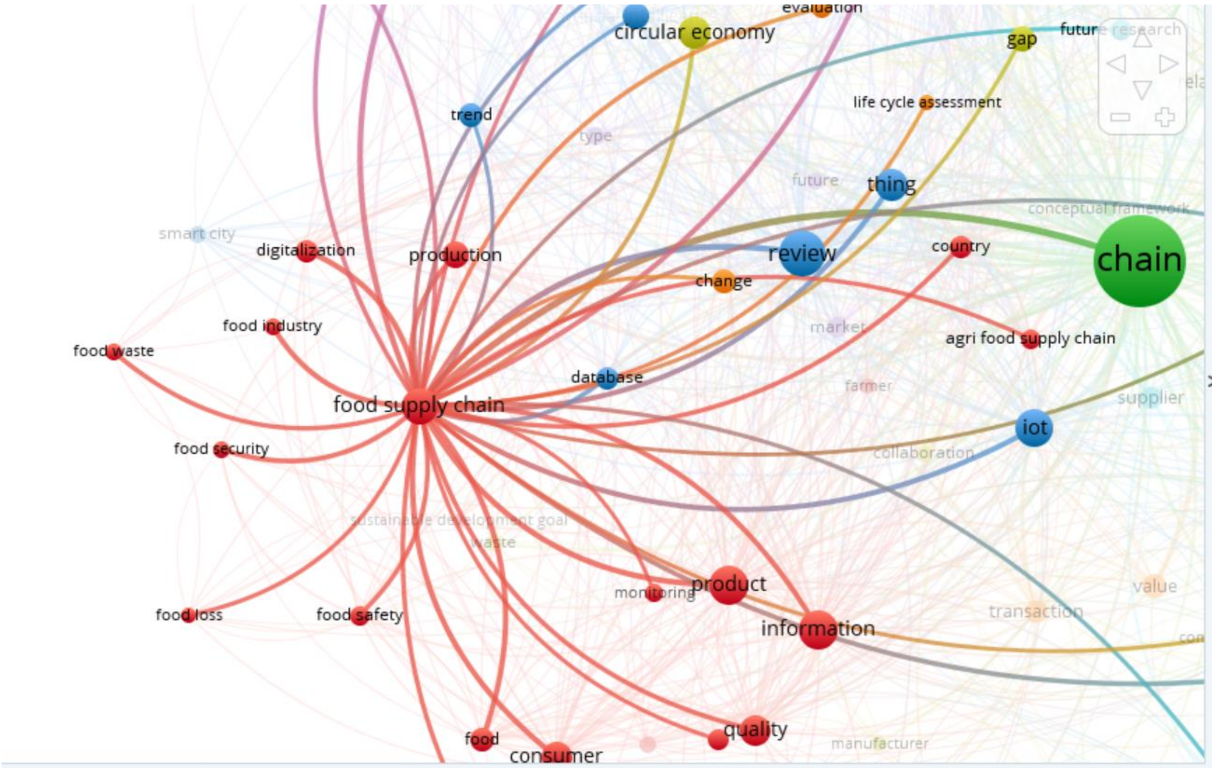

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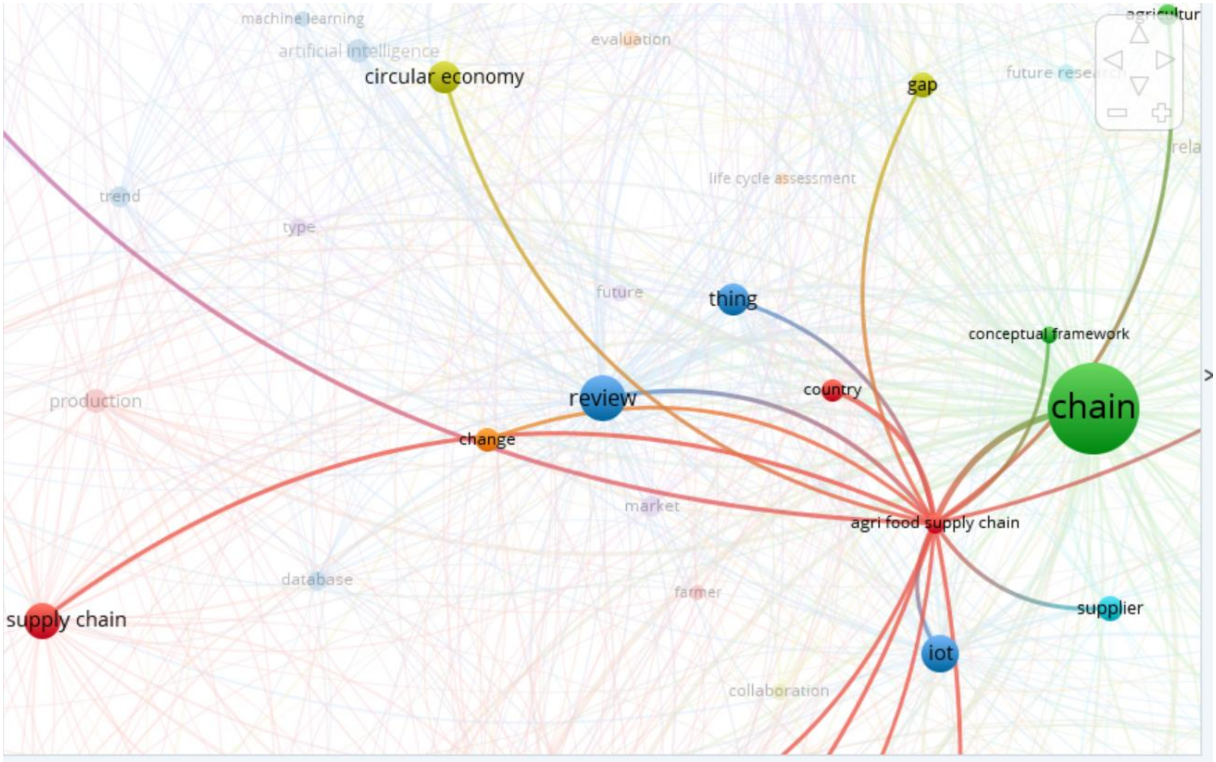
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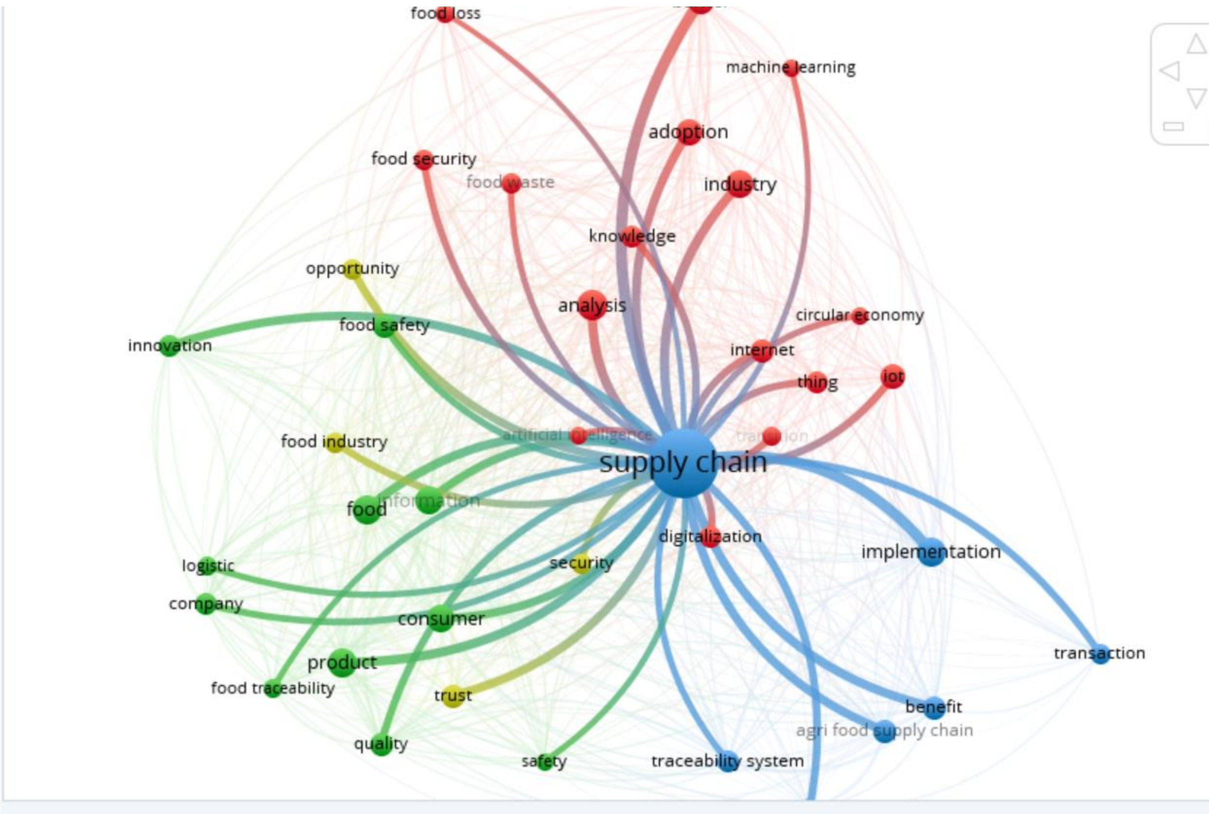
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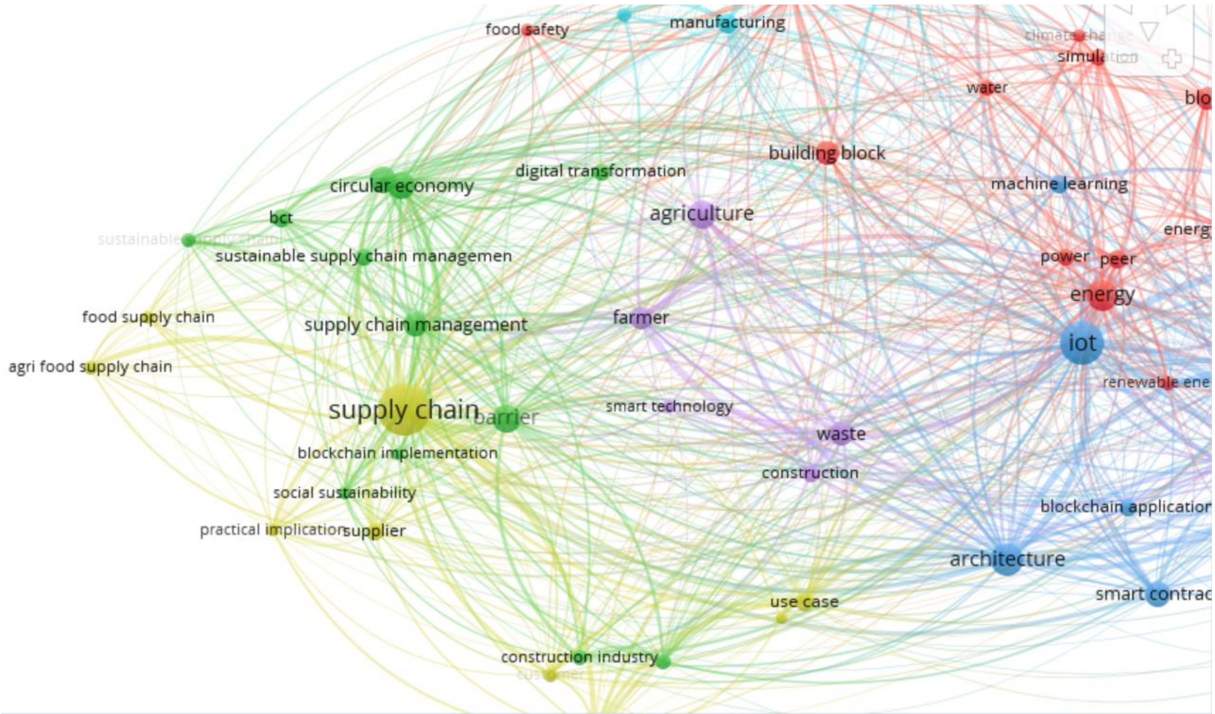
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