DOI: https://doi.org/10.14201/0AQ03112742

BLOCKCHAIN TECHNOLOGIES TO IMPLEMENT TRACEABILITY IN THE FARM TO FORK CHAINS

TECNOLOGÍAS BLOCKCHAIN PARA LA IMPLEMENTACIÓN DE LA TRAZABILIDAD EN LA CADENA DE VALOR DE LAS GRANJAS

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Abstract: Agriculture traceability demands a large volume of data that needs to be collected across the supply chain. Very early tracking and traceability systems used workers to record the information manually which entails risks, such as faulty information recording as well as inefficient resource usage. The implementation of tamper proof semi-automated digital ledgers will have a great impact on issues such as compliance with regulations, food provenance, food fraud, and many others, and therefore will gradually increase the trust within the supply chain. This paper provides an overview on the different stages of the AgriFood supply chain and of the fundamentals of a Distributed Ledger Technology, namely Blockchain, which can be used to mitigate some of the issues related to transparency and traceability of this sector. It also presents some solutions that already implement this technology to enable the traceability in the AgriFood sector. The authors also present the most important challenges and opportunities identify regarding the application of Blockchain based traceability systems for the AgriFood supply chain.

Keywords: blockchain; agrifood sector; traceability.

Resumen: La trazabilidad agrícola exige un gran volumen de datos que debe recopilarse en toda la cadena de suministro. Los primeros sistemas de seguimiento y trazabilidad utilizaban trabajadores para registrar la información manualmente, lo que conlleva riesgos como el registro defectuoso de la información, así como un uso ineficiente de los recursos. La implementación de libros de contabilidad digitales semiautomatizados a prueba de manipulaciones tendrá un gran impacto en cuestiones como el cumplimiento de la normativa, la procedencia de los alimentos, el fraude alimentario y muchos otros, por lo que aumentará gradualmente la confianza dentro de la cadena de suministro. Este documento ofrece una visión general de las diferentes etapas de la cadena de suministro agroalimentaria y de los fundamentos de una tecnología de que puede utilizarse para mitigar algunos de los problemas relacionados con la transparencia y la trazabilidad de este sector. También presenta algunas soluciones que ya implementan esta tecnología para permitir la trazabilidad en el sector agroalimentario. Los autores también presentan los retos más importantes y oportunidades identificados en relación con la aplicación de sistemas de trazabilidad basados en Blockchain para la cadena de suministro agroalimentaria.

Palabras clave: blockchain; sector agrifood; trazabilidad

1 Introduction

AgriFood Supply Chains are characterized for being ecosystems of high complexity and this is many times aggravated by the lack of transparency traceability. Existing systems lack in transparency and consumers' trust due to the unavailability of a fast and trustworthy way to retrieve information on the product's provenance. This problem can be mitigated by taking advantage of rapidly evolving technologies such as Information and Communication Technology (ICT), Radio-Frequency Identification (RFID), Internet of Things (IoT), Distributed Ledger Technology (DLT) and many more [4].

Additionally, today's consumer is a more informed, digital, and self-aware individual regarding the production conditions of the goods consumed. The nowadays consumer is interested in knowing, in a transparent and trustful way, about the practices used by the farmers (whether the farmers apply sustainable practices or not), the animal breed conditions, food provenance, and the transport conditions of the goods throughout the supply chain. This is true not only for the consumer, but transparent and trustful interactions between the different players of the AgriFood supply chain is also of great importance, facilitating the regulatory entities work and the prevention of fraud attempts.

The matters related to sustainable food systems are not only an interest of the consumers, the European Union has established the Farm to Fork Strategy which addresses comprehensively the challenges of sustainable food systems and recognises the relationships between healthy people, healthy societies and a healthy planet [6]. The Farm to Fork Strategy is at the heart of the Green Deal which offers a roadmap on how to make Europe the first climate-neutral continent by 2050. It maps a new, sustainable and inclusive growth strategy to boost the economy, improve people's health and quality of life, care for nature, and leave no one behind. In short, the Farm to Fork Strategy aims at building the food chain that works for consumers, producers, climate and environment by ensuring sustainable food production, food security, stimulating sustainable food processing, wholesale, retail, hospitality and food services practices, promoting sustainable food consumption, reducing food loss and waste and combating food fraud along the food supply chain.

Traceability systems can positively impact the AgriFood supply chain by allowing the decrease in the time needed to recall and withdraw products dangerous for the public health, thus improving consumers' safety and confidence. Additionally, traceability provides the agriculture supply chain with transparency and reliability, mandatory attributes considering the complexity of the food supply chain [4]. Despite the efforts of the different players of the AgriFood supply chain to developed technologies to track their products, in many cases the traceability systems are centralized, asymmetric and outdated in terms of data sharing and interoperability [4]. Leading the different stages of the AgriFood supply chain to continue to operate individually. In order to achieve a transparent and traceable system is mandatory to verify context data shared with third-parties, and guaranty the quality of data being stored in a distributed ledger. These are crucial requirements in applications the aim to certify the quality in food production, for example, the gathering of certain parameters of animal welfare on farms, or when public administrations strive to ensure transparency of their processes [7]. DLT offer a solution to many existing problems, but simultaneously pose new challenges as well.

For the above mentioned, DLT present great potential in the agriculture domain. The implementation of self-executing smart contracts together with automated payments would be the game changer. The role of smart contracts especially in agricultural insurance, green bonds, and traceability could be very effective [10].

In this paper the authors intend to present an overview on the importance of the traceability in the AgriFood sector and how DLT, particularly Blockchain, can be applied in this context, what are the challenges of its applications and what are the opportunities inherent for transparent and trustful traceability systems.

The rest of the paper is organized as follows: Section 2 introduces the AgriFood Supply Chain and the explains why the traceability is of great importance in this sector. Section 3 presents an overview of the Blockchain technologies, including the working principles, implementation technologies and some examples of application. The application of Blockchain technologies to the farm to fork chain is addressed in Section 4, where existing solutions for the AgriFood sector are presented. Additionally, the challenges and research opportunities inherent to the use of Blockchain technologies to the AgriFood supply chain are exposed as well. Finally, Section 5 rounds up the paper with conclusions and points out the future work.

2 Traceability in the Farm to Table Chain

Agrifood supply chains are characterize as a sequence of linked events associated to the agricultural production of food, including chain of events from production to processing, trading, distribution, and consumption [8].

The Agrifood supply chain includes, not only the producer and its suppliers, but also, depending on the logistic flows, transporters, warehouses, retailers, and consumers themselves [19].

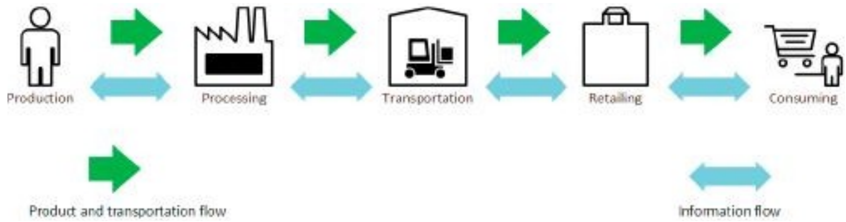


Fig. 1. AgriFood Supply Chain and its information flow [4].

The structure of the Agrifood chains are, as depited in Figure 1 initiated with the primary production of goods, which is diverse and includes production of crops, livestock, forestry, fisheries and aquaculture [9]. The resulting goods are then transported to the processing and packaging stage where the transformation industry intervenes. After this stage, the products are transported to the retail infrastructures (the goods can be stored in between these two stages) which sell the goods to the end user, constituting the last stage of the Agrifood chain.

Although the Agrifood sector has been adapting to all production, manufacturing and presentation standards, there is another characteristic that is strongly dictating trends in the markets: a more demanding, more informed, and digital end consumer. The main trends that will mark the future of the Agrifood sector worldwide are directly linked to product quality and environmental concerns. The search for new products, unique and innovative, has been an interest on the part of consumers, which has driven the evolution of the sector and companies. In parallel, the Agrifood value chain has to face consumer demands, norms and regulations for production, manufacture, labeling and food safety. On the other hand, international food law encourages the preservation of the history of production data, which led to the appearance of some traceability solutions resulting, for example, from regulatory and food safety requirements (DOP, BIO products, etc.). According to [2], food traceability can be definied as the ability to identify the origin of food and feed ingredients and food sources, particularly when products are found to be faulty. A traceability system allows an organization to document and/or to locate a product through the stages and operations involved in the manufacture, processing, distribution and handling of feed and food, from primary production to consumption.

However, these solutions and the information contained within these are disconnected throughout the Agrifood value chain, barely accessible to the other stages of the chain and, due to the fact that they are performed/registered mainly manually, result in a difficult consultation by the various economic agents throughout the Agrifood value chain and also by the end consumer. This difficulty penalizes quick action for example in situations of fraud. In this context, the BIOma project intends to address the challenges identified and promote the benefits of product traceability throughout the Agrifood value chain, by creating a digital, integrated and interoperable traceability solution that connects the different phases of the Agrifood value chain.

3 An Overview of Blockchain Technologies

This section aims to overview the Blockchain concept and working principles, providing also a fast snap-shoot on its technologies and applications.

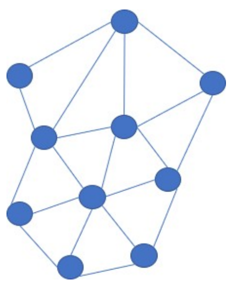
3.1 Concept and Working Principles

Blockchain is a disruptive technology for building consensus and trust in a peer-to-peer network without centralized control and it takes advantage of the DLT, which is a decentralized system for recording transactions with mechanisms for processing, validating and authorizing transactions that are then recorded on an immutable ledger [21].

A simple analogy for understanding Blockchain technology is a Google Doc. When a document is created and shared with a group of people, the document is distributed instead of copied or transferred. This creates a decentralized distribution chain that gives everyone access to the document at the same time. Non of users is locked out awaiting changes from another user, while all modifications to the document are being recorded in real-time, making changes completely transparent and it demonstrate tree critical ideas of technology:

1. Digital assets are distributed instead of copied or transferred.
2. The asset is decentralized, allowing full real-time access.
3. A transparent ledger of changes preserves integrity of the document, which creates trust in the asset.

Blockchain consensus algorithms ensure each new block added to the network is the only version of the truth, which is agreed by all the nodes in a decentralized computing network. There are four primary types of blockchains: Private and Public Blockchain and Consortium and Hybrid Blockchains which are variations of the first ones. Every Blockchain consists of a cluster of nodes functioning on a peer-to-peer (P2P) network system. Every node in a network has a copy of the shared ledger which gets updated timely. Each node can verify transactions, initiate or receive transactions, and create blocks. Publick Blockchain allow anyone to participate as users, miners, developers, or community members. All transactions that take place on public Blockchains are fully transparent, meaning that anyone can examine the transaction details [13].



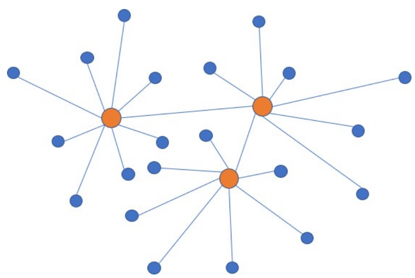


Fig. 2. Distributed structure. **Fig. 3.** Decentralized structure.

Before a transaction is considered valid, it must be authorized by each of its constituent nodes via the chain's consensus process. As long as each node abides by the specific stipulations of the protocol, their transactions can be validated, and thus add to the chain. Since each node on a public Blockchain has as much transmission and receipt power as any other, they are not only decentralized but fully distributed. The difference between distributed and decentralized structures is demonstrated in Figure 2 and Figure 3. Private Blockchains, also known as permissioned Blockchains, has a number of notable differences from public Blockchains. Private Blockchains are more centralized than public Blockchains so participants need consent to join the networks. Another difference of private Blockchain is that the transactions are private and are only available to ecosystem participants that have been given permission to join the network [5].

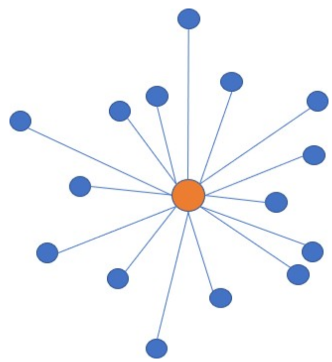


Fig. 4. Centralized structure.

In a centralized setup, a single entity has power over the system. In most cases, they can make changes at their discretion as there isn't some complex governance system for reaching consensus amongst many administrators. Meanwhile, in a decentralized setup, appearing challenges of agreement among entries in a distributed database.

Blockchain overcomes this challenge by resolving the trust issue between entities. Further, we'll be discussed how consensus algorithms are vital to the functioning of cryptocurrencies and distributed ledgers.

3.2 Blockchain Consensus Algorithms

As Blockchain functions in a decentralized manner and records large volume transactions in real-time, there may be the complexity of what the truth is. The key is to get consensus one way or another, or else double-spending attacks can occur. This is where the consensus algorithm comes in.

A consensus algorithm is a protocol through which all the parties of the Bockchain network come to a common agreement on the present data state of the ledger and be able to trust unknown peers in a distributed computing environment. For Blockchain networks, they are an essential element to maintain the integrity and security of these distributed computing systems [3].

In Blockchain networks, there is a wide variety of consensus algorithms, all with their own advantages and disadvantages. The two main kinds of consensus algorithms for arriving at a consensus in a distributed manner are Proof of Work (PoW) and Proof of Stake (PoS).

PoW is the first viable consensus algorithm and currently is the most common and one of the most robust consensus mechanism for Blockchain technology. In Blockchain, this algorithm is used to confirm transactions and produce new blocks to the chain. With PoW, miners compete against each other to complete transactions on the network and get rewarded [17].

The PoW method defines that the nodes must adopt the fork which carries work, and it is very unlikely that the two competing forks will generate the next block together. Blockchain core network protects against double-spending by the verification of each transaction with the use of PoW mechanism [18].

PoS is a substitute approach for PoW which requires fewer CPU computations for mining. Though this is also an algorithm, and the purpose is the same as PoW, the process is quite different here, especially during the validation of new blocks on the Blockchain network.

In PoS systems, the creator of a new block is chosen in a deterministic way, depending on its stake, or degree of commitment in the network. This means that in the PoS mechanism, there is no block reward. So, the miners take the transaction fees.

3.3 Example Applications

The Industrial Internet of Things (IIoT) plays a central role in the Fourth Industrial Revolution, with many specialists working towards implementing large scalable, reliable, and secure industrial environments. However, existing environments are lacking security standards and have limited resources per component which results in various security breaches. Due to the resilience and its security properties, combining Blockchain-based solutions with IIoT environments is gaining popularity [16].

Blockchain provides a way to securely and efficiently create a tamper-proof log of sensitive activity. This makes it excellent for international payments and money transfers. One of first applications based on Blockchain technologies are Bitcoin and other cryptocurrencies. It uses fully peer-to-peer networking technology to operate with no central authority or banks. Blockchain simply combines cryptography, distributed system technology and other well-known technologies. Besides, it also provides a secure framework for the cryptocurrencies, in which anyone cannot tamper the content of transactions and all the nodes participate in transactions anonymously [20]. Blockchain can be used to immutable record any number of data points as in the form of transactions, votes in an election, product inventories, state identifications, deeds to homes, and much more.

Similar to a transfer of value on a Blockchain, deployment of a smart contract on a Blockchain occurs by sending a transaction from a wallet for the Blockchain. A smart contract is a computer code that can be built into the Blockchain to facilitate, verify, or negotiate a contract agreement. Smart contracts operate under a set of conditions that users agree upon. When those conditions are met, the terms of the agreement are automatically carried out. Smart contracts permit trusted transactions and agreements to be carried out among disparate, anonymous parties without the need for a central authority, legal system, or external enforcement mechanism [11].

There are many other applications that can be built, all leveraging the benefits of Blockchain. From supply chain to accounting, to identity management, and more.

4 Application of Blockchain Technologies for the Farm to Fork Chains

This section presents the most interesting, in the authors perspective, Blockchain solutions for the AgriFood sector and what are the main challenges and research opportunities inherent to this research topic.

4.1 Existing Blockchain Solutions for AgriFood Sector

Enhancing traceability in the food supply chain is one known preventative measure and its wider implementation could help to check the spread of foodborne illnesses. The means and methods of increasing traceability exist and are in widespread use in many supply chains.

Walmart cooperating with IBM has launched a food safety Blockchain solution to add transparency to the decentralized food supply ecosystem by digitizing the food supply chain process. The food traceability system was created based on Hyperledger Fabric, the open-source ledger technology. By placing a supply chain on the Blockchain, it allows making the process more transparent and traceable. Each node on the Blockchain represents an entity that has handled the food on the way to the store, making it a lot easier and faster to see if one of the farms has sold an infected batch to a specific location [12].

Provenance uses Blockchain technology to track products through the AgriFood supply chain: materials, ingredients, and impact, in order to provide consumers with greater transparency about a product's authenticity and origin. Its use of the technology allows the end user to see each step of the journey the product has taken: where it is, who has it, and for how long? Producers can also benefit from this increased authenticity when telling the story of goods they produce [14].

Skuchain applies the cryptographic principles developed in the Bitcoin network to provide security and visibility for the global supply chain. As goods travel through the supply chain, from manufacturers to distributors to consumers, the crucial electronic information about what the item is and where it came from becomes disconnected from the stock keeping unit (SKU) itself. A Blockchain offers a universal, secure ledger by which SKUs can attest digitally to their origins and attributes. Skuchain is building a system of next generation identifiers in the form of both barcodes and radio frequency identification devices (RFID) tags to digitally secure the transfer of goods across the entire global economy. Whereas most anti-counterfeiting systems rely on copy resistant labels, holograms etc., Skuchain relies on the uncopyable nature of a Blockchain ledger to solve the problem of supply chain integrity. Skuchain's system will provide cryptographic proof of each SKU's origin and supply chain that can be verified all the way to the point of consumption [15].

Arc-net connects every step of a product's journey to deliver supply chain transparency and product security. The Arc-net toolset provides an easy to use scalable platform, powering the strategic insights that unlock profit. [1]

All the example provided above take advantage of the Blockchain technology in order to increase transparency throughout the AgriFood supply chain.

4.2 Challenges and Research Opportunities

Throughout the state of the art performed several challenges related to the implementation of Blockchain the AgriFood sector were identified. These challenges were organized in different groups as depicted in Figure 5.

There are several challenges to be addressed in order improve maturity and acceptance of this technology, some of the identified challenges are connected to technologies that are related to, and support, the use of Blockchain apply to the AgriFood sector. The most important challenges are divided into four main groups, namely technological, methodological, legislation and behavioural challenges.

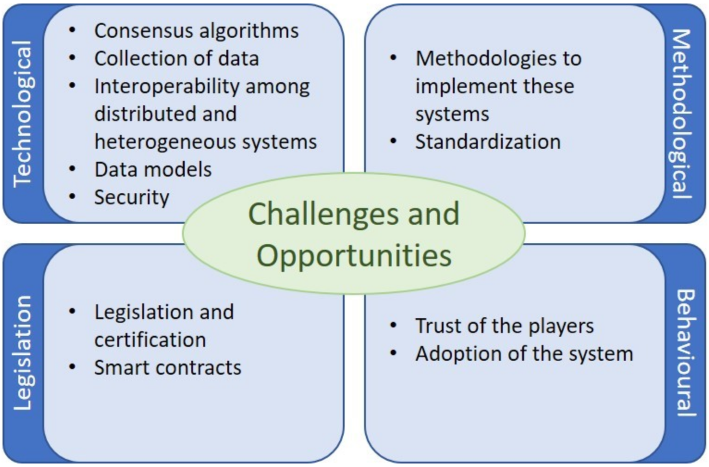


Fig. 5. Identified challenges and opportunities.

Regarding the technological challenges, the authors have identified the need to perform a benchmarking of existing technologies for the AgriFood requirements in order to understand how to take advantage of the best approaches and customize them for the AgriFood sector according the application requirements and constraints. The benchmarking must include a thorough study of the existing consensus algorithms to understand if the existing ones are compliant with the requirements of the AgriFood sector. These system are required to guarantee interoperability among distributed and heterogeneous systems, which can be a great challenge considering that such systems need to integrate data collected from different sources and formats. IoT nodes and communication protocols need to be considered to make sure that the collection of data is perform in accordance to their requirements. This leads to the study of the data models and the security on data transference from and to the Blockchain services. From a technological perspective the systems must be tamper proof as well as flexible and financially viable in order to improve acceptance.

The development and implementation of Blockchain is still in the early stages of its maturity and there are several methodologies to implement these systems creating a sense of uncertainty. Another issue that need urgent action is the lack of standardization. The authors have grouped these challenges under the methodological group.

The implementation of traceability systems in the AgriFood sector needs to be a subject of legislation and certification of the solutions. Also the implementation of the smart contracts is not yet regulated adding another layer of mistrust and contributing to the resistance to adoption of these systems.

All the challenges identified previously leads to the last group, the behavioural challenges group, which includes the lack of trust by the AgriFood chain players and the resistance in implementing Blockchain traceability system in their businesses.

Addressing the challenges presented in the other groups will contribute to the resolution of the lack of trust and consequently the increase the willing to adopt these systems. Last but not least, it is of great importance to increase the Technology Readiness Levels (TRL) level of the systems in order to move the prototypes and laboratory solutions from the experimental environments to the market.

5 Conclusions

Traceability systems are currently widely studied and considered to be applied to AgriFood supply chain since it can positively impact the sector by allowing the decrease in the time needed to recall and withdraw products dangerous for the public health, thus improving consumers' safety and confidence.

This paper presented an overview on the topics related to the application of DLT to the AgriFood sector, such as the description of the supply chain and how it would benefit of the application of traceability systems. Several topics regarding in inner works of Blockchain are exposed, namely the working principles and technologies used to implement it. Addicionally, the authors identified several existing solutions that take advantage of this technology to implement traceability in the AgriFood sector. All this work has converged in the identification of the several existing challenges of the application of Blockchain technology in the AgriFood sector. From the identified challenges was possible to recognize research opportunities.

Future work will be devoted to the structuring of a research work intended to contribute to further develop maturity of the Blockchain based AgriFood traceability systems.

Acknowledgments

This work has been supported by the European Regional Development Fund (ERDF) under the grant 46112 - BIOma (Soluções integradas de BI-Oeconomia para a Mobilização da cadeia Agroalimentar), and also partially supported by the European Regional Development Fund (ERDF) through the Interreg Spain-Portugal V-A Program (POCTEP) under grant 0677 DISRUPTIVE 2 E (Intensifying the activity of Digital Innovation Hubs within the PocTep region to boost the development of disruptive and last generation ICTs through crossborder cooperation).

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