UNIVERSITY OF LJUBLJANA

SCHOOL OF ECONOMICS AND BUSINESS

MASTER'S THESIS

DIGITALIZATION OF CROATIAN FAMILY FARMS THROUGH BLOCKCHAIN AND SMART CONTRACTS

Ljubljana, July 2023 Jakov Čevizović

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LIST OF ABBREVIATIONS

DeFi – decentralized finance

EU – European Union

CAGR – Compound Annual Growth Rate

IoT – Internet of things

ERP – enterprise resource planning

PLC – Product Life Cycle

EVM – Ethereum Virtual Machine

dApps – decentralized applications

SLNA – systemic literature network analysis

CNA – citation network analysis

SCM – supply chain management

SLR – systematic literature review

SSOT – single source of truth

DZS – Državni zavod za statistiku (eng. Bureau of Statistics)

INTRODUCTION

In the last couple of years, the World has witnessed the rapid development of several disruptive technologies such as blockchain, IoT devices, artificial intelligence, and many more. Ever since the invention of Bitcoin and blockchain by Satoshi Nakamoto, the crypto-community has seen many blockchain-based solutions that may shape and influence existing business processes in order to make them easier and more efficient (Pranto, Noman, Mahmud & Haque, 2021). Blockchain can be described as a digital ledger, that gained its popularity in 2018, together with other cryptocurrencies which are based on similar blockchain solutions. Due to the growing interest in blockchain, DeFI systems are on the brick of revolution of financial systems, mainly due to significant interest coming from retail investors (Stably, 2021). Such technologies are specifically known for their strong impact on the current monetary systems and for bringing new solutions in the form of the revolutionized stores of value – cryptocurrencies. The space of cryptocurrencies and blockchain has increased the interest of investors and businesses year by year, specifically followed by the massive bull markets[1] in 2013, 2017, and 2021. Currently, one of the most popular cryptocurrencies are Bitcoin, Ethereum, Cardano, and BNB coin while counting more than 22,000 different crypto projects that are trading at more than 500 exchanges (CoinMarketCap, 2023). Blockchain with other technological solutions such as the internet of things, big data, and smart contracts can serve as an underlying infrastructure for the development of new business proposals. Smart contracts were developed by Nick Szabo in 1994., but they were not used practically until the development of blockchain. Smart contracts can be explained as a structure of code, that is created on the blockchain or any other distributed infrastructure. As smart contracts are developed and transparently stored on the blockchain to primarily utilize the functions of transaction execution, their potential functionality can be made use of in many other industries such as supply chain. Smart contracts operate in a way that reduces the trust between the involved parties. When the coded predefined conditions in the contract are met, the blockchain will execute the smart contract, and without any external entities, the transparent transaction can occur (Ante, 2021), which represents a perfect usability case in the term of Croatian family-owned farms in their journey of digitalization.

Due to the effects of globalization and the fast-paced characteristics of current environments, which have become more complex as the number of participants in the supply chain has significantly increased where consequently the quality of the food has been impacted (Li, Lee, & Gharehgozli, 2021). Because of the blockchain's characteristics explained in the first chapter of the thesis, using such technologies is possible to mitigate such negative consequences. Blockchain can be used for refining the

[1] Bull market can be characterised as a positive trend and upward momentum of changes in price of financial instruments, the opposite of bull market is known as bear market (Maheu, McCurdy, & Song, 2012)

traceability of supply chains, reduction of document authentication time, providing more transparency during the construction processes, and streamlining payments (Figueiredo, Hammad, Haddad, & Tam, 2022).

The purpose of this master thesis is to provide a feasibility study from existing academic sources and field research to demonstrate how new and existing technological solutions can help underperforming economies such as Croatia, especially in the agricultural sector. The main goal is to put academic research into the practicality of Croatian family-owned business' and research the implementation of blockchain and smart contracts through the farmers' perspective and how it can impact the effectiveness of their existing traditional business processes. Due to the reason that such technologies can be new to farmers, the thesis will explain technological aspect of blockchain and smart contract, describing its effects and how farmers can used them for their advantage. The interview in the thesis will research the sentiment of owners of Croatian family farms, and whether their traditional farming approaches will get influenced by data-driven decisions.

Throughout the first chapter of the thesis, the focus will also be put on the usability of blockchain and smart contracts in agriculture, and the characteristics of owners of Croatian family farms, which are one of the subjects of the thesis. The author will also compare the state of Croatian agriculture with other countries from European Union. The second chapter of the thesis will be explaining the example of the blockchain architecture of a smart farm and how the Merkle tree in blockchain helps improve the traceability problems in the supply chain. Furthermore, it will focus on explaining the product life cycle, blockchain's and smart contract's immutability, and how to reach the single point of truth. The third chapter will give several practical examples of how practical mentioned technologies can be in agriculture and the supply chain, where each sub-chapter will follow up with the insights gathered from the interview with the farmers.

The subjects of the thesis can be explained through their mutual dependant relationship, where farmers act like producers in the supply chain and are in need of such technologies to help them with their lack of competitiveness which put them into unfavorable market positions. The second subject of this thesis is blockchain and smart contract technologies, based on which the author will make research and conclusion if such technologies can be implemented within the existing business processes of Croatian farmers. One of the most important dimensions of the economy is agriculture, so it is important that it constantly develops and successfully follows new technological trends. The food industry is no different and not reluctant to those changes. With increasing complexity and problems in the food supply chain industry, the doubt about the correctness of information from consumers has been increasing over and over time. Consumer awareness started increasing about the food that they eat, and consumer wants to be more informed. Alongside that, Croatian agriculture has been lacking in development and agricultural competitiveness in the market, although the country has been rich in agricultural fields, they have not been able to stay competitive in the market. With blockchain-based solutions in the agriculture and food supply chain, it can help to solve the problem of end-consumer concerns, increases safety and quality controls of the food, improve the trust between the farmers, and increase the knowledge of product life-cycle (Casino et al., 2020).

Considering the current academic research about the advantages and disadvantages of implementation of technologies such as blockchain and smart contracts within the supply chain and agriculture, it is possible to conclude the research problem for the thesis: "Traditional farming approaches of Croatian family-owned business can get affected by the implementation of disruptive technologies such as blockchain and smart contracts, and therefore it may help them mitigate problems such as loss of trust between intermediaries, transparency of prices and contracts, which might put them into more favorable position when competing in the EU markets."

The primary data for the thesis is collected for the purpose of getting sentiment information from Croatian farmers regarding their views and opinions towards the blockchain and smart contracts. The interview has been performed with three farmers, who wished to remain anonymous. The farmers are predominantly active in the business of cattle breeding, land work, and milk production. Farms are equipped with modern technologies used for milking and up-to-date machinery. The number of cattle present on the farm is in the range of 40 to 150 cattle per farm. Each farmer cultivates more than 100 ha of arable land, which makes them a suitable representative for the purpose of the thesis research.

1 CHARACTERISTICS OF BLOCKCHAIN, SMART CONTRACTS, AND AGRICULTURE IN CROATIA

The following chapter will provide the reader with the understanding of the proposed underlying blockchain technologies and smart contracts. For better understanding of characteristics of such technologies their advantages and disadvantages will be explained. To put Croatian family farms as a subject of the thesis, the reader will be informed with current state and problems that they are faced with, while giving insight into data such as; number of registered business, number of ha of arable land etc. Additionally, the current state of agriculture of Croatia will be compared with Slovenia and Netherlands.

1.1 Overview of previous research

The academic studies have written in detail about blockchain's wide applicability. In the research of Figueiredo, Hammad, Haddad, and Tam (2022), they have proposed efficient usability of distributed ledger technologies in achieving higher sustainability in the real estate and construction industry. The authors present the steps of how to achieve clean production and more efficient use of resources within the construction industry, which helps to achieve transparency in the construction processes and optimization of property sales. Furthermore, Santoso and Yulia (2021) extend the research of blockchain's usability study through the SWOT analysis to present the characteristics of blockchain based on the application to the supply chain, pharmaceutical industry, food industry, and automotive industry. The authors argue that it is essential that companies that are willing to implement blockchain in their daily operations have to perform a detailed comprehensive internal assessment. The companies can be faced with issues such as the level of market adoption, regulatory constraints, and dubious competitive advantage which might lead companies away from implementation of proposed technologies. Qian (2021) has presented an empirical study formed out of three dimensions; perceived trust, public satisfaction, and environmental characteristics regarding the blockchain's public adoption within the government systems that would possibly increase public participation through strengthening the security of government information and increasing public trust.

By explaining how blockchain is important in the healthcare industry because it mitigates the problems of the exchange of data within the healthcare ecosystem while improving trust and security, Hasselgren, Kralevska, Gligoroski, Pedersen, and Faxvaag (2020) presented research on blockchains implementation based on the cases if clinical trial and electronic health record systems. Regarding the thesis' topic, through the bibliometric and network approach analysis, Moosavi, Naeni, Fathollahi-Fard, and Fiore (2021) present noteworthy studies related to blockchain in the supply chain. A thorough analysis has shown the importance of transparency and traceability as one of the most important contributors to the implementation of blockchain within the existing supply chains. The author argues that blockchain strengthens the trust between the intermediaries in the supply chain, and improves information security and efficiency.

Regarding the traceability within the supply chain, Lekha, Chakaravarthi, and Visu (2018) show detailed architecture composed of QR codes that serve as an information-sharing service for consumers, where the consumers can obtain product information through the product ID information stored on the blockchain. Stored data can include; expiry date, date of production, level of storage temperature, etc. For more complex solutions than QR codes and RFID tags, Fernández-Caramés, Blanco-Novoa, Froiz-Míguez, and Fraga-Lamas (2019) propose the use of smart labels, which are good solutions in industry 4.0 for the detection of events and displaying of visual feedbacks. To furthermore understand the applicability of blockchain in food supply chains, Powell, Foth, Cao, and Natanelov (2022) go over the example of blockchain mechanisms with IoT devices that can be used in beef supply chains. The author goes over the importance of data integrity and data validity mechanisms, which are implemented through the designed blockchain architecture that involves Oracle devices, data (message) information, smart contract mechanisms, and other supply chain stakeholders.

Both Xu, Chong, and Chi (2021) and Lone and Naaz (2021) have conducted a detailed systematic literature review of articles related to smart contracts. Research from Lone and Naaz (2021) has shown that blockchain's smart contracts are mostly implemented to perform more secure services via the internet. The most prevalent smart contract services were data protection, authentication, integrity assurance, and the control of access to the data. Xu, Chong, and Chi (2021) research shows the list of application domains of smart contracts, their level of applicability, and in which Blockchain platform are they built. The data mostly shows that smart contracts are developed on the Ethereum platform and are applied in the healthcare, finance, supply chain, and IoT industry, while most of the smart contracts are still in the prototype phase or only as a proposed framework for current technologies. Ante (2021) provides a theoretical description of the development and history of smart contracts. Smart contracts were developed by Nick Szabo, and are described as computerized transaction protocol that functions through a way of satisfaction of the contractual conditions between the contracted parties. Smart contracts are very useful in payment terms, confidentiality, or enforcement, so therefore with their implementation they drastically reduce the need for third-party trusted intermediaries. Smart contracts mostly gained popularity when they were introduced on the Ethereum blockchain network by Vitalik Buterin.

For a better understanding of the Croatian position within the European Union and global trade, the research paper by Misir (2021) gives detailed insight into Croatian imports, export, and GDP data., Croatia imported around $4.2 billion of agricultural products only in 2020, and exported around $3.8 billion worth of products, resulting in a deficit of around $0.4 billion. The report also states that Croatia is overwhelmed huge backlog of cases in the judiciary system and complex and non-transparent bureaucracy. Additionally, the paper gives insight into Croatian aging popularity, stating that the average age of the population is 43.8 years old, with an increasing trend. A report written by EIB and EC (2020) shows that agricultural investments increased by more than 50% in the period from 2009 to 2016. Followed by the decreasing investments towards agriculture in Croatia, the farmers are required to renew their existing machinery and equipment, which are required if Croatia wants to balance out the production gap between the others in European Union. Through several graphical representations, the report shows the difficulties and problems that farmers are faced in Croatia in comparison to the EU. Croatian farmers have difficult access to arable land and financial loans required for investments and working capital, which significantly affects their competitiveness in the markets. In Croatia, the cost of production and low purchasing prices are still in an unfavorable position for farmers when comparing it to the other EU countries.

1.2 Development of blockchain and smart contracts

1.2.1 Blockchain

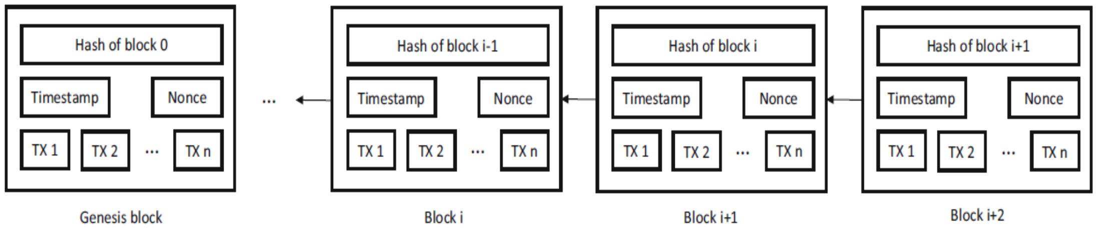
Ever since the invention of blockchain and Bitcoin in 2009, cryptocurrencies and DeFi innovations have been attracting many industries that were looking for new business opportunities. Quite recently, since many recognized the potential of such technologies to be applied across several industries, many companies have started researching and developing their blockchain projects (Viriyasitavat & Hoonsopon, 2019). At the moment, the applicability of blockchain applications expands far beyond the means of using it only as a platform for cryptocurrencies. The usability of blockchain spans a wide range of industries, mainly involving medicine and healthcare, insurance, IoT, economics, supply chain, etc. Since Bitcoin started as a peer-to-peer electronic cash system, the applicability of blockchain remains to be most popular in the financial industry (Nofer, Gomber, Hinz, & Schiereck, 2017).

The idea of blockchain was based and created on the consensus mechanism driven by the approach of information-sharing, broadcasting of public information, and elimination of third-party intermediaries among every transactions within the blockchain. The reason why businesses might pursue the implementation of blockchain is to revolutionize and improve their existing business processes because of blockchain's key characteristics and properties such as; immutability, integrity, and transparency (Viriyasitavat & Hoonsopon, 2019).

Blockchain's applicability is significant in many agricultural activities, such as the process of collecting the farmer's milk. As the milk is produced on the daily basis, it is important that blockchain stores real-time information that would help the user to determine the freshness of the milk that they consume. In the case of Croatian farmers, the collection of milk is typically performed by the dairy companies, which collect the milk usually after the morning milking processes. The information stored in blockchain during this processes can ensure that the consumers are using the milk that has been stored on the appropriate temperature and that the milk does not have any chemicals nor antibiotics. With having blockchain as an underlying architecture, it ensures the integrity of the data stored in the blocks due to its immutable features and improves the relationship of all stakeholders involved in supply chain.

The structure of a Blockchain is based on a combination of multiple data sets that together form a chain of data packages (blocks), where blocks are composed of multiple transactions that have happened on the blockchain. As it is a series of multiple data blocks, each block is added on top of another block and the relationship between the blocks enables the blockchain to be extended, which represents a complete digital ledger and the whole transaction history that ever existed on the blockchain (Nofer, Gomber, Hinz, & Schiereck, 2017). With such structure of interconnectedness and relationship between the blocks, the blockchain is able to ensures the data entry and validation without any third-party intermediaries. With proposition of such technologies to farmers, blockchain can ensure better traceability of farmer's products and improve data integrity which furthermore impacts the quality of food supply chains. With having unique hashes as a attribute to each stored block, supply chain stakeholders have increased security from potential hacking attacks and potential unwanted data modifications.

Figure 1. Visual representation of data blocks within the blockchain



Source: Nofer, Gomber, Hinz, and Schiereck (2017)

To make sure that each block in the blockchain is validated, the blockchain network uses cryptographic technology. Asymmetric cryptography is a way of communication technology that allows only the sender and recipient to see the content of the message. The information that has been sent out is encrypted via a public key, which can only be decoded using a private key. Relative to symmetric encryption, the process of decryption in the blockchain's example requires a public and private key (Wu & Duan, 2019). Except for the information about the transaction, the blocks are built out of data such as time-stamp, nonce (random number used for verification of a hash), and hash value that relates a current block to the previous block. By containing such information and data, blockchain through immutable blocks ensures integrity throughout the whole chain because of the existing first block, better known as the "genesis block", so, therefore, the information in the blockchain is immutable and cannot be changed due to the relationship between the blocks. Hash values are unique to each block and that helps in the effective detection and prevention of any potential frauds on the blockchain, which would immediately change the respective hash value of the block, which means that the whole chain would not be valid anymore (Pustisek, Zivic, & Kos, 2022).

For the new blocks to be added to the chain, the majority of the nodes in the blockchain have to agree by using the consensus mechanism based on the validation of the transactions in the block and on the existing validity based on the whole block. For example, in the proof-of-work consensus mechanism, validators can be described as computers that maintain integrity, and are usually known as miners (Wang et al., 2019). This means, that new transactions are not automatically added to the blockchain, but they have to go through the consensus process which makes sure that transactions that are expected to be added to the blockchain are stored in a block for a certain amount of time (approx. 10 minutes for Bitcoin blockchain) before they are transferred into the ledger. After they are transferred into the ledger, the information on the blockchain becomes immutable and cannot be changed anymore. In the example of Bitcoin, the blocks are created by miners, and they are rewarded with Bitcoin when validating the blocks. With the implementation of cryptography, the trust between the two parties increases, and the transfer of assets on the peer-to-peer network is more secure and easier over the internet (Nofer, Gomber, Hinz, & Schiereck, 2017).

As previously mentioned, blockchain has been witnessing wide ideas of innovative applicability across various industries. For instance, the implementation of blockchain has been proposed to British Columbia's health care data management to solve challenges and problems they were faced with their huge data information, potential security breaches, and unwillingness to share medical data. As such, hospitals can use different ERP systems to insert the data, where usually the import of data often lags up to 1 month, making the data updates not frequent, which therefore leads to inefficiencies and inconsistency in the flow of the information. The implementation of blockchain into the ERP system would bring new and improved trust and immutability functions (Cadoret, Kailas, Velmovitsky, Morita, & Igboeli, 2020). Similarly, in the explained case of healthcare, blockchain can also be useful in supply chain and logistics, where the benefits of blockchain in the supply chain are traceability and visibility of information that can be used for the estimation of the speed of shipping in the supply chain. With improved visibility of data in blockchian, it is an ability to see the information timely and accurate on supply chain, which can be of pivotal importance, which is a prerequisite of efficient information sharing and traceability in the SCM (van Hoek, 2019). Regarding traffic-based solutions, blockchain can be helpful in the creation of intelligent traffic systems that can effortlessly monitor real-time traffic conditions and locate any traffic emergencies. In the combination with IoT, the nodes can record any changes in the transportation system and via the blockchain, it is possible to create a credit-token paying mechanism that reflects the use of the transportation systems (Ren, Man, Li, Gao, & Ma, 2019).

1.2.2 Advantages and disadvantages of blockchain

Regarding the advantages of why should companies introduce blockchain to their existing business processes, most academic research argues that such technology is useful due to solving the issues of centralization and preaching its characteristics of decentralization. The introduction of blockchain acknowledges that no single authority can control the data stored in the blockchain, due to it being based on the peer-to-peer principle. That implies that transactions on the blockchain can happen without relying on trust between the parties. Through the blockchain, the parties that are executing the transaction can use the blockchain as an underlying infrastructure as the verifier in the transaction (Matyskevic & Kremer-Matyskevic, 2021). Such characteristics of blockchain can specifically be useful in agriculture and supply chain because it reduces the need for third parties, and reduces the risks of lack of trust between the supply chain stakeholders.

Since the blockchain can be public, no information cannot be hidden from the public which remarkably increases transparency where the customers can become aware and more informed of what food they consume, and it also contributes to the decrease of opportunities for suppliers to mislead the information about the production and distribution of the food. With blockchain being public and with the improved transparency throughout the lifecycle of the product, it simultaneously causes greater contribution to increasing the quality of the goods and services produced (Gatteschi, Lamberti, Demartini, Pranteda, & Santamaria, 2018a).

The validity of the blockchain can be secured with the hashes from previous blocks, as the creation of a new block requires a hash from the previous block. Blockhain's approach to the connectedness of blocks reduces the undesirable changes and makes it secure while also ensuring that there would not be any redundant changes on the chain. As each action on the blockchain is recorded and available to each party, it brings to the importance of immutability, which means that the data on the blockchain cannot be changed and that it always stays the same. There are shared records and processes of the business that can be shared and cannot be changed, therefore trust is increased if the implementation of the blockchain is successful. If the transactions are executed through the blockchain, they cannot be changed or deleted anymore. On the contrary, if the system would be centralized, the transactions could be changed or deleted since it relies on one single person. This characteristic of blockchain brings value to it being unalterable and indestructible. The transactions in the blockchain are still relatively cheaper when compared to the traditional cross-border payments if the money transfer is sent through the bank cable transfer, which is particularly useful in the supply chain because of the required transactions across different countries and continents. Blockchain is open and functions every hour throughout the week, which reduces the delay of banking transactions (Golosova & Romanovs, 2018).

Concerning the disadvantages of such technologies, blockchain is mostly criticized because of its high energy consumption. Blockchain requires energy for keeping the ledger in real-time because in this way it creates communication between nodes and it brings value to transparency. The nodes that are created make sure that the data is stored in the blockchain, that it minimizes the risk of failure, and makes sure that there is no downtime. Due to these high-performing activities, the blockchain requires a significant amount of energy to be driven (Golosova & Romanovs, 2018). The mining process required to create the Bitcoin consumers roughly about 91 terawatt-hours of electricity on annual basis, which is more electricity than is used by Finland (Huang, O'neill, & Tabuchi, 2021). Since data entered into blockchain is immutable and in the case of input of false data, it may lead to additional costs because the information of the blocks cannot be changed so therefore the correct data has to be inputted again which consequently impacts the consumption of the power. In case in which smart farms would deal with high amounts of data, the input of incorrect information on blockchain poses a financial liability to the business (Mardus, 2018).

Consequently, with the high consumption of power, blockchain transactions can be costly, so therefore they might not be affordable. With the consideration of high energy consumption by the nodes, the Bitcoin transaction can cost up to $6 per transaction. With the high cost of the transactions, the miners also require expensive mining equipment. Due to the lower supply of GPUs needed for mining cryptocurrencies, the prices of GPUs dramatically increased, and it was hard to enter the market and make value through mining because the entry costs were expensive (Gatteschi, Lamberti, Demartini, Pranteda, & Santamaria, 2018b).

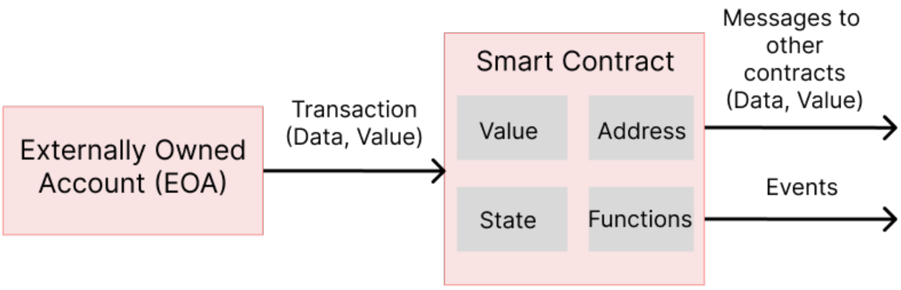
Each blockchain has a different amount of time to create a new block in the blockchain. For example, the information in the Bitcoin block needs from 10 to 60 minutes to be added, while the Ethereum information needs around 15 seconds to be added. This means that not every transaction can be efficient and it can impose other problems, such as delays. Additionally, with blockchain's characteristics of being transparent and immutable, it could pose harm to the user's reputation and their private information due to the privacy laws and GDRP (Gatteschi, Lamberti, Demartini, Pranteda, & Santamaria, 2018b).

1.2.3 Smart Contracts

In correlation with the development of Bitcoin and blockchain, we have witnessed increased popularity of the creation of smart contracts, mainly leading in the financial industry. These contracts are event-driven programs combined out of tamper-resistant, self-execution, and self-verification properties (Mohanta, Panda, & Jena, 2018). Traditionally, financial transactions between the sender and receiver were performed through trusted intermediaries, but with the introduction of blockchain, their functionality has become obsolete and redundant. Third parties were mainly used because of a lack of trust. To increase the trust in the transaction, people had the confidence that intermediaries will store and protect their goods and capital, and that they will send the right amount to the receiver when requested. However, by transferring trust to decentralized systems, blockchain can be used to replace the functionality of intermediary parties. For instance, lawyers and central banks are prime examples of the functions that are affected the most by the blockchain. Blockchain servers as a solution, because it introduces a concept of being charged per item, rather than being charged per hour when the function is requested. Furthermore, the transactions performed through third parties can often be delayed and costly, consequently taking more time to be executed, and can also result in higher security problems due to the single point of failure. To solve the mentioned problems, smart contracts were invented. Smart contracts can be explained as digital contracts, described as value flows that are based on specific terms and conditions written inside that contract. Smart contracts "imitate" the contracts in the real world, except they do not exist in written form, but are written in the programming codes and are automatically executed when the conditions are met. They are small programming codes stored inside the blockchain and can be implemented on many different blockchain platforms. The most popular one is Ethereum, whose smart contracts are written in the Solidity programming language (Macrinici, Cartofeanu, & Gao, 2018). But, the term smart contract was invented a long time before the blockchain and Bitcoin.

In 1994., Nick Szabo defined the smart contract as a computerized transaction protocol that is used to satisfy contracted conditions like payment terms or enforcement by bringing down expectations and removing the need for trusted intermediaries. Later on, Szabo defines smart contracts as the combination of different protocols on the user interfaces that guarantee formal and secure relationships between the parties on different networks. Szabo has built this theory on several technical, economic, and legal foundations. The founder of Ethereum, Vitalik Buterin has played a crucial role in the implementation of smart contracts within the applicability of the blockchain industry. Contrary to Szabo, Buterin says that smart contracts are consisted of deceiving names and that they rarely represent a legally binding construct. On the blockchain, smart contracts are represented as simple computer language codes that do not only represent any legal contract but are simply executed on the predefined logic that has to be met. They are computer codes that can contain legalese properties, which helps them to know in what way they have to act based on the predefined logic that can be based on the legal structure. Smart contracts can be performed through the partial execution of legalese across the computer code within the contract, where the code bears the resemblance of the legalese (Ante, 2021). To have a valid smart contract, it is advised that each of them is composed of the following components; contractual obligation between the parties, governance of preconditions, and execution of the contract. The contractual agreement and obligations within the smart contract can be negotiated and communicated through a programming code. On the blockchain, each subjected party in the contract is recognized by their wallets and transactions that present fulfilled obligations that are transacted among those blockchain accounts/wallets, while simultaneously allowing such codes to be stored in the distributed blockchain (Sillaber & Waltl, 2017).

Figure 2. Smart contract structure



Source: Mohanta, Panda, and Jena (2018)

Regarding the applicability of smart contracts, academic research shows that smart contracts can mostly be used in agriculture, business, supply chain, manufacturing, finance, healthcare, etc. For example, if smart contracts can be implemented in the financial and public management industry, they can play a significant role in reducing corruption and embezzlement (de Souza, Luciano, & Wiedenhöft, 2018). Smart contracts can also automate the bidding processes, which automatically proves the identity of both the bidder and bidding entities. In the voting systems, smart contracts ensure the fairness of the voting. In healthcare, with the use of smart contracts, they can ensure the rights of data sharing without the problems of data leakage, ensuring safe peer-to-peer data transfer. In the supply chain, smart contracts perform the transactions automatically, and in the logistics, they can enable secure monitoring of procurement workflows (decisions and documents), which strengthens the immutability and provides real-time traceability of the goods and transactions (Xu, Chong, & Chi, 2021).

Figure 3. Example of code for a smart contract in the compensation context of insurance

```
function treatment Payment (address addr) public {
        require (msg.sender== insurance);
        if (patient[addr]. patient Payment==0||!patient[addr]. raise Right) return;
        patient[addr]. insurance Payment += patient[addr]. patient Payment;
}
```

Source: Ge (2021)

To ensure the correct implementation of smart contracts, Sillaber and Waltl (2017) presented the framework for the life cycle of decentralized smart contracts, which are based on blockchain technology. The suggested holistic life cycle consists of the following stages:

- Create
- Freeze
- Execute
- Finalize

During the "*Create*" phase of the contract's life cycle, it is required that parties negotiate the objectives and content of the contract, where all contracted parties should have an account on the decentralized ledger platform. After the parties have agreed on the contracts' conditions, it is important that the conditions are transferred into the programming code. The contracts are developed on a platform that allows for contracts to be developed, tested, and maintained. After the contract is programmed, parties should submit the contract to the distributed ledger (publication stage). Due to smart contracts being decentralized, changes to such contracts are not possible after they have been published, and the changes to the contract would require the creation of a new contract. After the contract has been published, it enters into the "Freeze" stage where the content of the contract undergoes the control of the miners, where the fee is paid to miners to prevent the flooding of the ecosystem. Nodes are checking the obligations of the contract and that the preconditions of the contract are met and any transfers of the smart contract are frozen.

When the participating nodes check the content and obligations of the contract, the contract is executed by the smart contract environment and it validates the contract's integrity. The "*Execute*" phase of the contract is a new transaction as a new state of the smart contract. When the contract is executed, the new state information is sent to distributed ledger and is validated by the different consensus protocols. When the contracts are executed, transactions become new state information and are stored in the distributed ledger, and confirmed by consensus protocol, where the smart contract enters into the last stage called "*Finalize*". Contracted assets are unfrozen and transferred as the confirmation that the contract has been fulfilled by all parties, and it ensures safe transactions between the parties (Sillaber & Waltl, 2017).

1.2.4 Advantages and disadvantages of smart contracts

Smart contracts are mainly known for their automatization and cost decreases, which cut down the administrative and service costs of many businesses. The feature of smart contracts is that it is a technology that automatically enforces, fulfills, and negotiates the predefined terms of the contract. Because of their automation, similarly to the blockchain, they do not require the third party to supervise the processes of smart contract activation, which creates more trust between the parties without supervision. This helps to make a digital transformation of existing conventional practices (Xu, Chong, & Chi, 2021).

If the contracts are successfully deployed onto the virtual environment, the terms and conditions of the contract become visible to everyone within the specific blockchain, which significantly improves communication and transparency between the parties. Nodes in the blockchain can be used to monitor the transactions from one party to another party. Smart contracts decrease fraud, as everything is controlled by nodes. Contracts like this, reduce the chances of breaking the contract before time, not following the rules of the contract, and breach of terms and conditions (Allam, 2018).

Regarding the smart contracts not being able to be changed once they are deployed, Gilcrest and Carvalho (2018) argue that blockchain and smart contracts with the use of cryptography provide immutability, which brings the uncensored source of truth. That means that, regardless of the outcome of the smart contract, not a single party can alter the history and change it in their favor. Because they are immutable, it allows for an easier audit of the information stored in the smart contract.

Currently, smart contracts may pose a problem because the initiator cannot observe the signals that trigger the contract to be executed. For instance, what if the transferred good is damaged or the second party does not receive it? In this case, the contract itself becomes inflexible and no recourse is possible, which means that such contracts can lead to new inefficiencies. Because of that, the terms in the contracts have to be defined perfectly, which means that due to the decentralization, it may still require third-party performance checks (Meier & Sannajust, 2020).

Using smart contracts in an environment that is not stable, or in an uncertain virtual environment can pose new costs, therefore it may increase the operational costs of the business (Meier & Sannajust, 2020). Similarly, to the blockchain, as they are stored within the blockchain, the smart contracts become public and can be seen by the public, which may pose threat to the privacy issues related to GDPR or expose business secrets and transactions to the public. Smart contracts expose the content of the business transactions to every node in the blockchain network, which is required for them to get validated and executed (Christidis & Devetsikiotis, 2016).

Smart contracts are still in the early stage of development, so therefore it is hard to find the workforce and skilled people. There is a need for programming skills so that the code is understandable and that it aligns with the law. Furthermore, the time for companies to see if their investment is paid off is usually long, which means that they will have to wait for a few years, to see if they made the correct business decision to switch to the blockchain. The technology is not mature yet, and it is hard to find the proper blockchain environment that will fulfill the industry's needs. As smart contracts are immutable, even though it is considered an advantage, they can still be a threat because, hackers might exploit bugs in the code to steal the money (Gatteschi, Lamberti, Demartini, Pranteda, & Santamaría, 2018b).

1.3 How blockchain and smart contracts can be used in agriculture

The supply chain connects different stakeholders and customers through the stable and regular flow of information, capital goods, and materials. It is a complex process that is dependent on the good relationships between the stakeholders through which they are trying to overcome challenges such as lack of trust between stakeholders, flaws in information sharing, incoordination, etc. (Rodrigues et al., 2021). Information sharing is crucial in both agriculture and the food supply chain industry, where it is important to align the incentives of all stakeholders throughout the whole cycle. Sharing of partial information can usually result in miscommunication and misrepresentation of current product demand which results in the bullwhip effect[2] (Ghode, Yadav, Jain, & Soni, 2020).

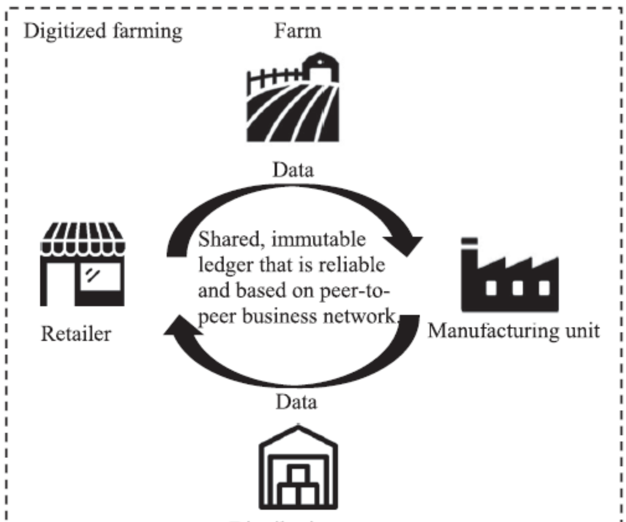
The stakeholders that are important in this process are producers (farmers), distributors, retailers, and consumers. The reason that different stakeholders are usually located in different regions, or even different continents, makes it very difficult to solve the lack of transparency and trust problems, which therefore makes product tracing challenging and inefficient. To have effective blockchain architecture that may align the needs of all stakeholders, it is required to build a peer-to-peer network inside the supply chain, that could enable all stakeholders to communicate with each other via a set of different IoT sensors (Moudoud, Cherkaoui, & Khoukhi, 2019). Within the supply chain industry, the implementation of such technologies can help in the prevention of fraud and the conduction of information asymmetry that helps in improving goods tracking and increasing transparency and confidentiality. Furthermore, such technologies also ensure

[2] Bullwhip effect is a phenomenon present in supply chains and describes how possible fluctations in demand on the retail level can cause the bigger fluctations in the demand from material suppliers, manufacturers or distributors (Daniel, 2023)

better data security and accountability. Since blockchain is a decentralized protocol based on the interconnectivity of computers, it brings automation to such procedures, reducing unnecessary bureaucracy documentation, which simplifies payment procedures and information sharing. Additionally, the sharing of information expands the knowledge of farmers and other stakeholders regarding the use of future technologies. Since blockchain in the supply chain can improve the transparency of exchanged goods, the customers gain knowledge of their products from beginning to end, which therefore positively impacts the trust between the consumers and producers. With such impacts, the blockchain can influence the inflow of foreign investment into the country (Rodrigues et al., 2021). Such transparency within the supply chains allows positive changes in the extent of the voluntary availability of information to the stakeholders within and outside of supply chain. For instance, such data usually consists of more detailed information about specific business processes, cost analysis and the origin of products for consumers.

The reports from research have shown that more than 30% of food is lost or wasted due to the food supply chains being inefficient. Additionally, we have counterfeit food, which can make it look like the producers are using expensive viring oil, but instead, the manufacturers add artificial flavors. Research shows that 10% of food sold is spoiled and not of the best quality. Blockchain allows both tangible and intangible assets to be traded via blockchain, ensuring their integrity via smart contracts (Li, Lee, & Gharehgozli, 2021).

Figure 4. Representation of blockchain in the agricultural supply chain



Source: Li, Lee, and Gharehgozli (2021)

In digitalized farming, to avoid misinterpretation of information it is important that the communication from producer to consumers is aligned, and that all stakeholders have efficient participation in the supply chain. For example, producers can provide information that concerns agricultural procedures, crops, usage of pesticides and fertilizers, specifics about the crop cultivation processes, animals and their well-being, etc. The processors in the supply chain would be available to provide the data about the underlying transactions within the supply chain, that would occur between the producers and distributors. The distributors would be able to give detailed information about the shipping information, storage conditions, and transit duration of specific transportation stages. Retailers that would sell the goods can provide the consumers with the specifics of the goods, such as; the quality of the food, expiration dates, the time that goods have spent on the shelves, storage conditions, etc. With such information when making purchase decisions, consumers can make rational decisions when purchasing goods. In the final stage of the supply chain, the consumers can obtain the information associated with the specific good by accessing it via QR code or through Web access (Li, Lee, & Gharehgozli, 2021).

When considering the principles of SCM and agriculture, it is important to understand how crucial of value the transparency of information is, the relationship between consumers and suppliers, customer service, and the quality of goods sold to consumers. Every stakeholder within the chain has to assure specific requirements for the supply chain to be fulfilled and that the efficiency throughout the chain is improved and satisfied. Therefore, information technologies can play a significant importance to supply chain and agriculture, where such technologies would be able to bring value to increase competitiveness with the implementation of cyber connectivity between different business processes in these two industries. Agriculture is heavily dependent on efficient supply chains because it is responsible for transportation of the goods from producer to consumer. The quality of agricultural products might be affected due to the slow and low flow of information in supply chains, because of many obstacles and challenges that are present. For instance, delays, distortions, inefficiency, inaccuracies, etc. One of the solutions to how those problems can be solved through the implementation of the blockchain (Rodrigues, Lourenzani, & Satolo, 2021).

Together with the blockchain, the application of smart contracts in the supply chain will allow automated, proper, and distributed workflows while diminishing human possible errors. They will digitally facilitate, verify and enforce the performance of the contracts within the blockchain. Smart contracts can be composed of different clauses that can be triggered fully or partially through self-executing programming codes, depending on the conditions that are specified within the contract. Incorporated within the smart contracts, the stakeholders can facilitate the use of different oracles (hardware or software oracles that collect data from the physical world) through which the decision of whether to trigger a contract or not can be made. Additionally, mentioned oracles will take the collected information and distribute the currency or token through the smart contract which is based on the information flow collected through such oracles (De Giovanni, 2020).

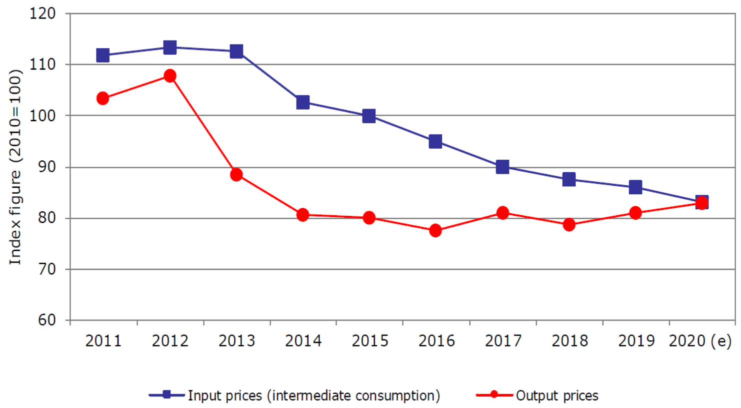
1.4 The state of agriculture in Croatia

Agricultural family businesses' in Croatia are one of the crucial components of the organizational and economical aspect of agriculture in Croatia, making them one of the most important initiators of the economical development of the country's governmental units (Dreven, 2020).

Despite the prosperous diversity of ecosystems and agricultural conditions¸ Croatian agriculture has been faced with a decreasing long-term trend, that consequently resulted in the dependence on the high food import. The current state of Croatian agriculture can be described as unused potential, categorized with low competitiveness in the EU's market which is a direct consequence of small and fragmented land parcels, low technological development, and undeveloped market infrastructure. Therefore, the approach how to increase Croatia's competitiveness in the EU's agricultural market is to focus on the technological development and marketing of family farms, to strengthen their bargaining power in the food market and the global food supply chain industry (Nedanov & Žutinić, 2015).

According to the last updated annual report (2020) of the conditions of agriculture by the Ministry of Agriculture (2021), it is stated the COVID-19 pandemic significantly affected all the segments of the industry, including the development, employment, supply chain, and consumers, which lead to a significant drop in the GDP. But with several fiscal and monetary stimulus measures, the negative consequences were downsized. Since the pandemic had a severe hit on agriculture as well, the government encouraged the development of digitalization, and through better information sharing with local consumers the demand for local goods has increased and it slightly suppressed the negative effects resulting in the increase of the GDP and productivity in the agricultural sector. Therefore, the value of GDP has increased by 3.3%. The prices of goods and services have stayed the same as in 2020., while food prices have increased by 1.8% when compared to the previous year. Net trade in 2020. has decreased, where exports fell by 2.1% and imports decreased by 8.3% (Ministry of Agriculture, 2021).

Figure 5. Comparison of input and output prices of Croatian agriculture



Source: European Commission (2021)

The Figure 5. shows that throughout the last decade, the input prices of agricultural economic accounts of Croatian farms have significantly decreased, and have reached the same point of value as output prices. With the decreased input prices, Croatian farmers are using fewer factors for their production, such as labor, equipment and machinery, and raw materials. Regardless of having low input prices, the Croatian farmers have managed to slightly improve their stagnant outprices level, meaning that their finished products are not very competitive on the international markets. The reason why input prices have decreased might be related to the decreasing number of registered businesses, lower amount of arable land, and aging population.

Table 1. GDP in Croatia expressed in billion of US dollars per year

	2012.	2013.	2014.	2015.	2016.	2017.	2018.	2019.	2020.	2021.
GDP	57.37	59.03	59.42	50.24	52.4	56.32	62.32	62.33	57.47	68.96

Source: Trading Economics (2022)

With the data from World Bank in Table 2., the Croatian economy has witnessed major fluctuations in the positive and upward trend of the GDP development. The major role in the increase of GDP from the period of 2020. until 2021., was the impact of the reopening of the country after the COVID-19 pandemic, and the historic earnings of the tourism season. It is possible to conclude that agriculture had little to none of the impact on increasing the GDP.

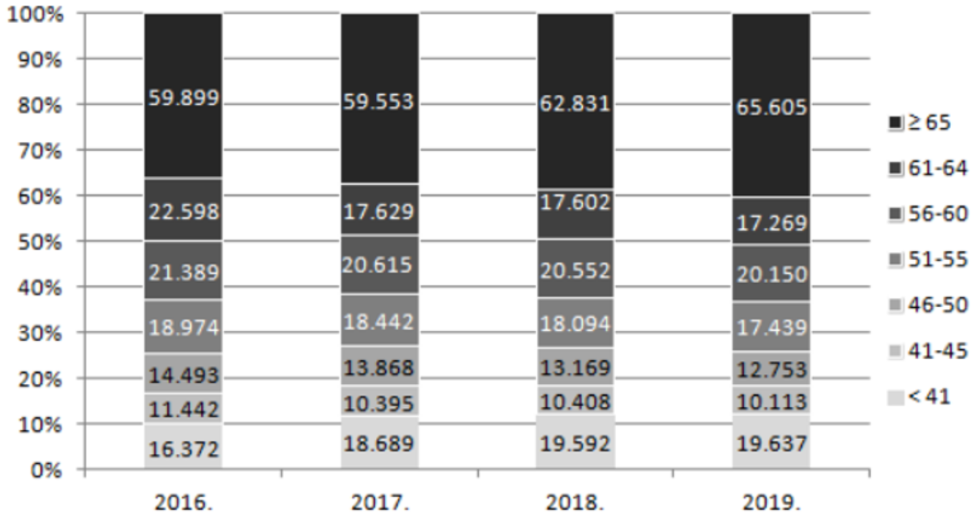
Table 2. Number of registered agricultural businesses in Croatia

	2007.	2010.	2013.	2016.
Family-owned business	181.250	233.280	157.450	134.459
Family-owned business with animals	162.260	194.090	123.080	88.131

Izvor: DZS (2022)

Based on the GDP data from Trading Economics (2022) and the numbers of registered family-owned businesses from DZS (2022), it is possible to conclude that Croatia has suffered a big downfall in the number of registered family businesses. The statistics show that the number of registered family business have peaked in 2010., counting more than 230.000 registered businesses, and fell to 134.459 registered businesses in 2016, which is a decrease of 42,4%. A number of family-owned businesses with animals have faced a similar situation. The number of registered businesses fell from 194.090 in 2010., to 88.131 registered businesses in 2016, which is a decrease of 54,6%. Since the fall of registered businesses does not directly correlate with the changes in the GDP, it is possible to conclude that other factors are responsible for negative changes in the number of registered businesses.

Figure 6. Age of owners of Croatian family businesses in the period from 2016 to 2019



Source: APPRRR (2022)

Based on the information from Table 6., the data shows that throughout of period from 2016. – 2019., the majority of registered family owners are above 60 years, which is of significant concern, because the majority of Croatian agriculture relies on agricultural foundations based on the older population. The Croatian Government should implement policies where they would focus on encouraging and promoting agriculture to younger populations.

Table 3. The amount of arable land in Croatia divided by categories in the period 2001-2021

	2001.	2005.	2009.	2013.	2018.	2020.	2021.
Ploughland and gardens	848.642	864.830	863.023	874.863	803.902	888.928	856.738
Lawns	254.708	265.238	343.306	618.070	607.555	536.683	539.596
Orchards, vineyards, olive groves	68.559	72.307	86.343	73.082	71.645	77.782	77.401
Other	44.225	56.688	43.976	33.345	25.881	5.812	2.616
Total	1.216.134	1.259.063	1.336.648	1.599.360	1.508.983	1.509.205	1.476.351

Source: DZS (2022)

According to the information from the Croatian Bureau of Statistics, from 2013., Croatia is witnessing a slight decrease in arable land. In 2013., in total Croatia had 1.599.360 ha of arable land, while in 2021., it has around 1.476.351 arable land, which is a decrease of 123.009ha, counting the ha of ploughland, lawns, orchards, olive groves, and others. The biggest share of arable land in Croatia is in the Eastern part of the country, called Slavonia, and the smallest amount of arable land is in the Northern and Southern coastal areas, while Mountain Croatia has the highest amount of uncultivated arable land. This segmentation of arable land in Croatia is the consequence of the geographical position of the country being inter-related to social geographical processes, which can be seen in the example of uncultivated land of mountain Croatia part. Ploughland can be mostly seen in Central Croatia, while lawns and grasslands can be seen in Mountain Croatia, while vineyards and orchards are mostly representative of South and Northern coastal areas (Dreven, 2020).

Such segmentation of the arable land restricts Croatian farmers from further development, because they are unable to have bigger lands under their ownership which impacts the amount of food that they can produce. Additionally, since a lot of land is uncultivated and unaccessable because of unfavorable positions, farmers are limited on the amount of the land that they have on their disposal. Consequentyl, table 4. shows that the number of a family-owned business' in Croatia predominantly have between 2-9,9ha available for production of their crops. Small amounts of arable land per registered family-owned business restricts Croatian farmers to compete on international markets because of the limited production capacity and unfavorable position at the global supply chains. Blockchain would not be able to solve the problem of segmentation of the land, but instead it might allow Croatian famers to have a new and innovative approach to the future agicultural processes. Specifically, the data that would be stored within the blockchain can allow farmers to make new and informed data-driven decisions based on the analytical approach to the historial data related to the crops yields and different ecological conditions of the fields, since they are limited in the amount of diposable arrable land. With the access to such data, the Croatian farmers could impact the amount of production that would help them to better utilize available fields.

Table 4. Number of Croatian family-owned agricultural businesses divided by the classes of the amount of arable land in the year 2016

	Number of a family-owned business
Without arable land	1.785
< 2 ha	50.806
2 – 4,9 ha	40.840
5 – 9,9 ha	20.079
10 – 19,9 ha	9.466
>= 20 ha	11.483
Total	134.459

DZS (2016)

According to Rački-Kristić (2020), Croatia has around 400.000 ha of uncultivated land that is at its disposal to become useful land for food production. Such land is left uncultivated and is not used. Another problem is that Croatia still has some mines in the fields from the Homeland war that pose a problem, so due to security reasons, specific lands cannot be accessed before they are cleared out. Based on the analysis from dr. sc. Vladimir Kušan where 1 ha of land can feed around 27 people, the 400 000 ha of land can be used to feed more than 11 million people on annual basis. With such numbers, Croatia is significantly lacking in the export of their agricultural products, and the resources are not used efficiently (Rački-Kristić, 2020).

1.5 Comparison of Croatian with the Netherlands and Slovenia

The Netherlands and Slovenia are compared with Croatia to show how countries with the bigger and lower amount of arable land are standing in the terms of global trade. The Netherlands is chosen due to its famous agricultural products and big exports to the World, and Slovenia is picked due to its similar historical developments and geographical position.

Table 5. Data of trade balance of Croatia, Netherlands and Slovenia in the year 2018

Country	Trade Partner	Trade Balance (US$ Thousands)	Export (US$ Thousands)	Import (US$ Thousands)	Arable land (in ha)
Croatia	Europe	-8.479.097	15.472.837	23.951.934	803.902
	World	-9.104.707	16.991.280	26.095.988	
Netherlands	Europe	125.193.860	415.792.437	290.598.577	1.021.000
	World	67.264.261	551.352.792	484.088.530	
Slovenia	Europe	5.332.136	34.593.470	29.261.334	181.780
	World	958.425	37.471.094	36.512.669	

Source: WITS (2022)

When comparing the state of agriculture and economy of Croatia with other countries of the European Union, it is safe to consider that Croatia is lacking in digitalization, since it still relies on the bureaucratic approaches in governmental agencies. Since the digitalization of traditional approaches might have an indirect impact on Slovenian and Dutch development of economy, Croatia is still stuck with traditional bureaucratic approaches that frequently delay development procedures. The digitalization and reengineering of the business process systems in the Netherlands and Slovenia has an impact on the business procedures which directly makes them less complex and timeextensive, which allows them to shift their focus more towards the goal of the business and not to lose resources on exhaustive traditional processes.

As Croatia has around 803.902 ha of arable ploughland, it is not taking advantage of it at full capacity. With such an amount of land at its disposal, Croatia still has a negative trade balance and is importing food, making it inefficient. For instance, Slovenia with only 181.780 ha of arable land has a trade balance of $5.33B and is making sure that they are making the most out of every resource that they have. In comparison with Slovenia, Croatia has a 622.122 ha higher amount of arable land. In the example of Slovenia, even though such an amount of land cannot be enough to heavily rely on domestic agricultural production, it still makes an impressive impact on Slovenian agricultural production. Everywhere across the country, it is possible to see stands with domestic goods that promote domestic production, in both cities and villages.

When comparing Croatia with the Netherlands, in which the Dutch agricultural sector mostly focuses on the production of cereals (wheat) and maize. In the Netherlands, the agricultural sector exports more than $70 billion of agricultural goods on annual basis, which makes it about 17.5% of their total exports (Ministry of Agriculture, 2022). Right after the United States, the Netherlands is the second biggest exporter of agricultural goods in the world and is heavily focused on sustainable agriculture, which makes them competitive and efficient in the market (Whiting, 2019). Duch agriculture is putting a lot of focus on the savings of energy and animal welfare over the next few years. Together with government subsidies, farmers and entrepreneurs are able to energize multifunctional agriculture, where they are combining agriculture with care and nature management (Ministry of Agriculture, 2022). With the high focus of Dutch agriculture towards the greenhouse sources for energy and organic farming, Croatia with its traditional way of utilizing land resources has limited power for competition.

Additionally, in March 2017. the project “Blockchain for Agrifood” was started in Netherlands which was financed by the Dutch Ministry of Agriculture, Nature and Food Quality, where the aim was to gain better understanding of blockchain technology and its implications towards the agrifood, and what aspects of supply chain are needed to apply blockchain technologies in agrifood chains. From the pilot study in the Dutch agrifood, it is possible to conclude that blockchain technologies allow the Dutch farmers to have lower transaction costs and more reliable data. Blockchain technologies improve the added value to food products because of increased transparency and assurance of provenanve of information, while at the same time having a direct contact with the consumers. With the projects like this, the Dutch government shows how it is ready to implement certain disruptive technologies in case they can help Dutch farmers in achieving better competitiveness and brining digitalization in traditional business processes (Ge, Brewster, Spek, Smeenk & Top, 2017).

2 ANALYSIS OF HOW TO MAKE FOOD MORE SECURE WITH BLOCKCHAIN AND SMART CONTRACTS

Second chapter gives in-depth information of the necessary technological architecture built around blockchain to support the supply chain industry, the chapter will also describe the role and what kind of information different stakeholders within the supply chain can share in order to provide the end-consumers with more information. The subchapters 2.2-2.3 will explain how data can be stored with Merkle tree structure to achieve traceability within the blockchain, and how such tracking can be achieved throughout the product's life cycle. Furthermore, the subchapter 2.4 will give an insight of security and its constraints within the smart contracts.

2.1 Blockchain architecture within the supply chain industry

According to Moudoud, Cherkaoui, and Khoukhi (2019), to enable the implementation of blockchain in the supply chain industry, there is a need to build an efficient blockchain architecture around smart contracts that require low computational power, optimization of latency, and efficient storage capability. To enable efficient architecture of such technologies, there is a requirement to combine specific technological components; IoT, blockchain, and smart contracts. Because each of these technologies bears some kind of disadvantages, the users can benefit more from their usability if they are used in the combination with each other because that additionally enhances their efficiency. For instance, IoT devices can have problems such as security, data integrity, and trustworthiness, these devices cannot be used on an individual basis especially when the collected data reflects private and business-related information and is shared between different individuals.

By implementing blockchain in an architecture that consists of IoT devices, such problems can be mitigated. In cases like this, the third party that validates the data and trustworthiness becomes redundant. To avoid the problem of high power consumption and IoT's limited resources, it is possible to implement smart contracts and Oracles. Additionally, for blockchain to be secure, it requires the definition of "openness" and the ability of the non-members of the blockchain regarding their access to the stored data. For such blockchain architectures, several solutions can be proposed:

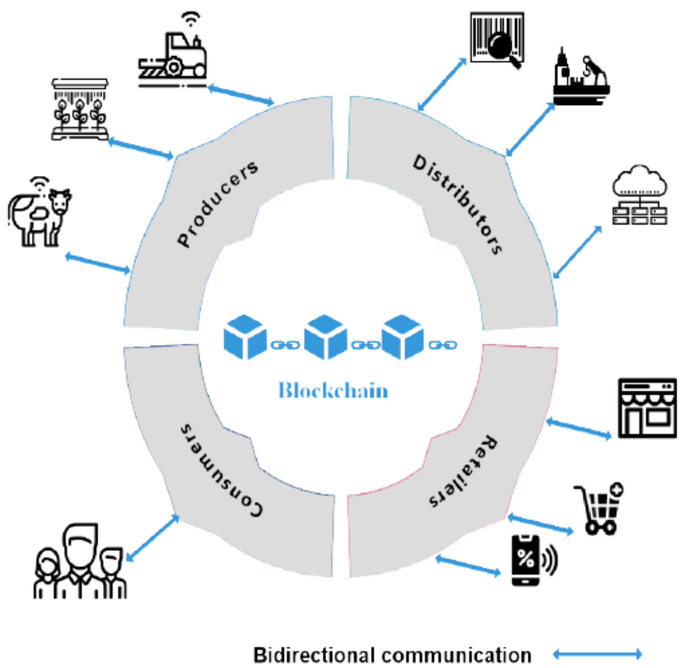
- only members of the blockchain can get access to data/data is restricted to the public (private)

- everyone can view data stored on blockchain/data is not restricted to the public (public)

Regardless of the access to the data stored in the blockchain, the consensus of the blockchain should not be compute-intensive, so that it ensures efficient work and energy savings. To ensure efficiency, smart contracts can be put into practice, where the relationship between different stakeholders can be applied, and where work is divided among them, by introducing different policies and rules that get triggered based on rules written in smart contracts. To verify the data, oracles can be used as third-party verification agents for the data that cannot be fetched or reached directly by the blockchain, in other words, Oracles can be used to verify the data that is coming from the physical world, or from sensors (Moudoud, Cherkaoui, & Khoukhi, 2019).

Moudoud, Cherkaoui, and Khoukhi (2019) have proposed a secure architecture structure where blockchain can be used with IoT in such a way that it can be used in the supply chain industry and agriculture. Knowing how the supply chain in the food industry consists of multiple stakeholders, starting from farmers and continuing to distributors, and retailers and finishing with end-consumers, such supply chains can become very complex. Because of globalization and trade between countries, these stakeholders can be in several different regions across the world before the product reaches the consumers, and due to low trust and transparency among them, product tracing becomes really difficult (Li, Lee, & Gharehgozli, 2021). In situations like this, blockchain can be used for permanent records of data that provide real-time access to such information and solves the problem of traceability. For such a proposal to work, architecture has to consist of; an IoT network, Cloud, Oracle’s network, and smart farms.

Figure 7. Example of food supply chain stakeholders within the blockchain technologies



Source: Moudoud, Cherkaoui, and Khoukhi (2019)

The elemental IoT network includes all the supply chain members, where the underlying network forms a network that is distributed among all the stakeholders involved in the process. The peer-to-peer network is built on top of the supply chain system, which then enables the communication between all the supply chain stakeholders. Each member of the chain is initialized at the beginning and validated by their public key. If a new member wants to be added to the chain, it has to be approved by "quorum", which represents the least number of members required to reach an agreement. In this layer of the architecture, the implementation of smart contracts ensures the rules and policies, and that is respected by all the parties in the chain. Smart contracts can be developed by third parties which can be responsible for ensuring transparency and efficiency of stored data within the chain, and implementation of governing operations between the relationships of stakeholders (Moudoud, Cherkaoui, & Khoukhi, 2019).

For farms to be included in the architecture, they have to implement IoT devices, blockchain, storage, and proxy nodes. As previously mentioned, blockchain can be of different ledger types; private, public, or consortium. Private blockchain allows access to the data only to the network members, while public blockchain allows everyone to join the network and every member is responsible for the validation of the transactions. Regarding the purpose of the application of blockchain, both private and public blockchains can be useful within farms. Within the consortium blockchain, which is not fully decentralized, only specific members are responsible for consensus determination. It is a type of blockchain that can be built by several organizations. But, for the proposed architecture, the best way is to use the combination of private and public blockchains, where the private blockchain is used to store private information, while the public blockchain is used for product tracking and for allowing the general public to access the data (Moudoud, Cherkaoui, & Khoukhi, 2019).

Since the data in the supply chain will be connected with the sensors from different locations, the Oracles can be used for checking the accuracy of collected data through the sensors. For instance, an Oracle can be used to send information such as; if the temperature inside a refrigerated track used for the transportation journey of products has been above or below a certain temperature threshold (Li, Lee, & Gharehgozli, 2021).

The other crucial part of the architecture is the cloud, which is used for storing the raw data that has been received and collected from Oracles' network. Data in the cloud can be public, which ensures data transparency or it can be private with limited and restricted access to ensure the privacy of the stakeholders which are involved. In the food supply chain example, the stakeholder will be assigned a public key, for personal Could space usage. With the public key used to access the Cloud data and information, it ensures that the source is identified and that data is correctly routed. To ensure non-repudiation and trustworthiness, the authors proposed using the private blockchain (Moudoud, Cherkaoui, & Khoukhi, 2019).

To add the transactions to a blockchain, miners are required to verify a certain condition. It is a three-step process, where firstly, miners need to verify the sender's signature to validate the authenticity of the transaction, for which they use the public key stored in the transaction. Secondly, miners need to perform certain checks of the predefined public keys, to see whether the sender's public key has a transaction in a blockchain or not (if it is a part of the genesis transaction or not). At last, miners are required to check and verify the Oracles' signatures used in the network. When all conditions are met and validated, data and transactions become transferred to the transaction pool for mining (Moudoud, Cherkaoui, & Khoukhi, 2019).

In such architecture, the blockchain is used as a mediator in the data transfer process. The data can be sent to the receiver within the transaction in a blockchain (i.e. Bitcoin), or information can be sent within the smart contract (i.e. Ethereum). To solve the problem of block size limitation, the data can be stored on-chain and off-chain. This means, that if "Farmer A" wants to send specific information or data to "Participant" in blockchain, "Farmer A" has to perform data storage within the Cloud. Then, "Farmer A" can be validated and identified by his personal public key, the private key which is a secret, and the address that he will use for storing the data. Since the blockchain has limitations regarding the sizes of the blocks, the such obstacle can be mitigated in a way where "Farmer A" stores metadata on-chain and the actual data off-chain. To share the data with "Participant", "Farmer A" is required to share the public key with "Participant" which uses the key for encryption of metadata with the public key. When the transaction is executed, it needs to be signed with the "Farmer's A" private key. The nodes within the network will start verifying the state of the transaction, with the verification of the personal signatures and public keys of both receiver and sender of the information. When all steps of the procedure are finished, the transaction is added to the verified transaction pool. A node in this example acts like a miner. The miners inside the network choose a transaction from the pool to create a block. Then miners will attempt to reach a consensus to append a block. The first miner who reaches a consensus will broadcast the new block to other miners, and the transaction becomes a permanent part of the ledger, where "Participant" can now have access to the address where "Farmer A" has stored data with her private key (Moudoud, Cherkaoui, & Khoukhi, 2019).

2.2 Analyzing the Merkle tree to explain traceability

Agriculture has seen an uprising trend of implementation of IoT devices that are trying to mitigate the problems of product traceability, which is of crucial importance to consumers. With the implementation of IoT devices, consumers can get more reliable historical information regarding the production and storage of the food and crops that they purchase and consume. As previously mentioned, blockchain solves the problems of data security, reliability, and integrity due to its immutable characteristics, but how can it solve the problems of traceability?

According to the Chun-Ting, Meng-Ju, Nen-Fu, Jhong-Ting, and Jia-Jung (2020), the system design for an efficient traceability approach to goods in agriculture has to be created out of 3 layers:

- data collecting layer

- blockchain layer

- application layer

Due to the reason of having a backup of the data of the whole platform, the system has to be appropriate and suitable for big amounts of data and performing verification by comparing the current data with the data in the backup. Since such activities can be very costly and time-consuming, the best way to solve them is to use the Merkle tree data structure as a storing format.

Merkle tree can be described as a tree structure which is consisted of non-leaf nodes that store the cryptographic hash of each of the children nodes, and the leaf nodes that store the hash of the data that is intended to be confirmed. With the Merkle tree, it is possible to perform the top-down data-confirming search, which is significantly reducing the time for verifying the data.

Figure 8. The hash value of the i-th node:

$$H_i = \begin{cases} f(C_0, C_1 \ldots C_h) & ,h > 0 \\ f(D_i) & ,h = 0 \end{cases}$$

Source: Chun-Ting, Meng-Ju, Nen-Fu, Jhong-Ting, and Jia-Jung (2020)

Co to Ch – child nodes of the targeting node
h – total number of children
Di – data to be used for leaf nodes
f – the function that hashes all inputs into unique and irreversible hash code

For such purpose, it is advised to use the SHA256 algorithm that creates a 64-digit hash code. If there are changes in the input data, it can cause an immense difference in the output hash code. Since it has this characteristic, and if the root hash of the two different Merkle trees is the same, then it can be guaranteed that the data of all the leaf nodes from these two Merkle trees have no differences and are the same.

When the user is requesting the data of a specific time range from the IoT device, it is possible to format such data within the Merkle tree structure to compare it with already formed Merkle tree by the data of that specific time range which was previously backed up on the private blockchain. By using such an approach, the users can enable swift tracking of the existing hashes of nodes that can be used in the detection of tampered data.

For easier data analysis and data insights of the collected information from the IoT sensors that are implemented on the farm or agricultural field, the collected data is assigned with sensor id, timestamp, and value. Within the first level in the Merkle tree, from the JSON objects we have formatted 64-digit hash code. The second level of the Merkle tree is responsible for the allocation of the data with its sensors id, and hashing the data from the sensor into one. Furthermore, in the third level, hashes coming from each sensor and within the same group are once again hashed into one and are allocated with their group id. The fourth and fifth levels in the Merkle tree have similar functionality. Within the same period of time, the data that is collected by the same sensor is hashed, which is then additionally hashed into the parent hash, allocating it to the sensor is used for the collection of data. Such a procedure can be repeated until the root node of the tree is reached for getting a complete JSON format.

To ensure the immutability for additional data verification, the Merkle tree is stored in a data section of a specific transaction that is being executed. With the implementation of smart contracts, which are transactions executed based on specific conditions, they store a set of protocols for nodes that they need to follow in order to obtain the information. Data is usually structured in the combination of maps and arrays and provided functions for their modification. Regarding the genesis block within the chain, it is the first block in every existing blockchain and is required for created of the block network. The nodes cannot add new blocks to the blockchain if the genesis block is not exact and the exact same chain number. If the genesis block is the same, the nodes are able to synchronize the data and are able to become functional within the blockchain network.

To enable connection to the blockchain network, the users need to use specific Web3 packages. With the functions such as sendTransaction, getTransactionByHash, etc. users are able to easily exploit blockchain network requests. In most cases of Web3 packages, for the development of applications and for providing certain functions, the developers mainly use the JavaScript framework. To compare and query the data from the existing data collecting layer and the data within the blockchain layer, to avoid using arrays, it is possible to employ a Merkle tree data structure for storing the hashes of the data. Because of the characteristics such as integrity, availability, and confidentiality, it is possible to ensure the security of information that is stored within the blockchain network. With such components and tools, it creates a simple model in a blockchain that solves the problem of traceability in agriculture (Chun-Ting, Meng-Ju, Nen-Fu, Jhong-Ting, & Jia-Jung, 2020).

2.3 Description of product life cycle tracking with blockchain

For improving the quality of the offered goods and services, it is important to track the goods across every phase of the product's life cycle. Understanding the product life cycle is important because it improves the innovation of the product, reduces costs, improves quality, and reduces communication gaps in the chain. The product life cycle can be divided into four phases; introduction, growth, maturity, and decline (Kenneth Udokporo, 2021). In a product's life cycle, the goods go from being unknown to customers to their market peak and decline in the terms of demand. During these phases, it is advised to collect customer data, through which the suppliers and producers can make efficient decision-making to prolong the growth and maturity stages and delay the decline in demand. To know how products "behave" in the markets, the family-owned farms specifically have to invest in promotion and attractive prices to compete in the markets. At the beginning of the product's life cycle, companies are usually faced with a lack of data, which can be solved with smart contracts and blockchain. To make the data-informed decision, they need to account for the data and information about consumer involvement, environmental factors, and food trends. It is important that family-owned farms monitor the data collected during PLC to analyze and recognize the forces that impact the products from the introduction to the decline phase, and whether those forces have a positive or negative impact on the product life cycles management (Horvat, Granato, Fogliano, & Luning, 2019).

The reason why blockchain should be implemented in the product life cycle is due to its characteristics that enable knowledge and information sharing across all stakeholders. With implementation of blockchain technologies, the communication between the stakeholders is not time-consuming anymore, and it also improves security. Having such technologes as underlying technology will lead to better decision-making and better productivity among the stakeholders. It enables open and clear communication between all the stakeholders from production and factories, business networks, and customers. The integration of such technologies helps to better utilize the resources and allows the stakeholders to create a value chain for analysis.

The proposed architecture of product life cycle tracking has to be created in the 5 stages;

- perception layer
- off-chain layer
- blockchain layer
- application layer
- service layer

Within those 5 stages of the PLC, it is important to account for the changes and impacts of different factors such as; marketing, design, manufacturing, packaging, warehouse & logistics, consumption and maintenance, product recycling, and reuse. Throughout these factors and stages, it is crucial that providers of goods ensure fast and responsive search of product tracing, maintenance of products, and product recycling. The perception layer is significant due to its importance in inputting sources of the proposed platform. The layer is used to collect the data in the product life cycle environment, ranging from transportation to manufacturing and warehouse. The perception layer is composed of IoT devices, RFID tags, sensors, QR codes, and GPS systems. Data collected in the perception layer is transferred to the cloud via the smart gateway (middleware between IoT and cloud). Further on, the collected data for the purpose of the analysis is transmitted to the off-chain layer, so that it can be submitted to the blockchain network.

Data that has been transmitted to the off-chain layer has to go through data cleaning, data validation, and data broadcasting. After those processes, the final hash is created with the blockchain keys, and the data is broadcasted to the blockchain network. Additionally, it has to be approved by certain consensus algorithms, which then store the hash value in the blockchain.

Within the blockchain network layer, together will already mention smart contracts, will contain DAPPs, consensus protocols, and cryptography. Each of these software products within the blockchain has different functionality and different role in the product's life cycle. For example, with different SCM systems and enterprise resource planning software, different information and data about products can be tracked quickly and accurately.

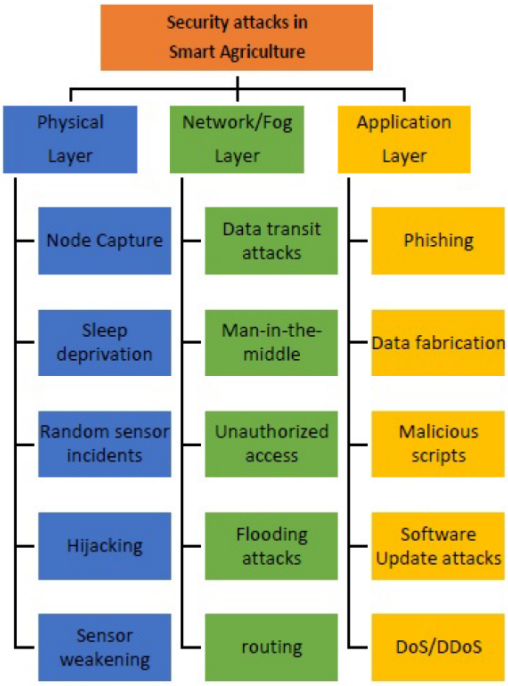
Within the service layer, we have services such as; product recycling, product maintenance, real-time tracking and tracing, and product creation. We have different processes varying from marketing to maintenance and logistics, that have to be coordinated together to guarantee the safety of the product and its quality. Also, to provide a proactive product service, the blockchain can be used to record and report the feedback from the end-consumers, which would allow quicker reactions (Liu et al., 2020).

2.4 Security and immutability of data inside smart contracts and blockchain

With the increase of IoT technology for real-time data reporting and automation in smart farming, the security and privacy within the architecture model of IoT networks within the blockchain and smart contract environment are a significant challenge that is widely discussed in academia and industry. With the huge amounts of data transmitted through IoT devices and applications are of sensitive nature and can pose a risk to the business. Since IoT in combination with smart contracts and blockchain has a wide adaptation, each industry faces different security issues that have to be tackled. If the privacy and security issues are solved, the applications on the blockchain become more reliable and efficient to the end users, increasing their satisfaction and trust.

The proposed architecture systems by Mohanta, Chedup, and Dehury (2021) requires the security concepts such as; availability, integrity, and confidentiality. Also, the applications in the network need to have access controls and authentication systems. In smart agriculture, the architecture has three layers, and each of the layers is subject to different security challenges:

Figure 9. Possible security issues of smart contracts in smart agriculture



Source: Mohanta, Chedup, and Dehury (2021)

Within the physical layer, IoT devices in the network are usually targeted by outside attackers, because of the low processing and computation power that they have, which makes them vulnerable and an easy target. In the network layer, the most significant are risks of unauthorized access, man-in-the-middle, and routing attacks, where the attackers are trying to obtain the information through unstable communication channels (this problem can be solved by encrypting data when it is sent to the receiver side). But, since the IoT devices send the information to each other as well, there is also a high risk of phishing, data fabrication, DDoS attacks, and many more. The goal of the attacker is to make the system insecure to try to obtain certain information or to just make it unable to use. The introduction of blockchain to the supply chain architecture, permits data modification and changes since the blocks within the blockchain are related and dependent on the correctness of the previous block hash. The immutability of blockchain makes the attacks such as phishing, man-in-the-middle, malicious scripts, and routing hard to execute. Other characteristics of blockchain that increase its securities are; peer-to-peer transactions, decentralization, consensus mechanism, validation, mining, and cryptography hashes (Mohanta, Chedup, & Dehury, 2021). In the blockchain, for the identification of nodes, it is possible to use digital signature and hashing, while the cryptography of the public key can be used for the transmission of messages between the nodes and to the blockchain network. With transparent smart contracts, not a single participant within the chain will be able to change the contract, which ensures immutability in the blockchain and supply chain industry. With such characteristics, the implementation of blockchain in smart agriculture brings benefits such as; better management of trust, accountability, and transparency. Additionally, IoT can help detect fraud and establish more control over agricultural markets.

2.5 How to make quality information with a single point of truth

When the researchers usually mention the single point of truth, it is mostly related to electronic health records and how is data stored in databases. SSOT in information science is the practice and models which are related to data schemas for data normalization and data storage. Similarly to EHRs, SSOT principles have to be followed in supply chains, especially in agriculture due to the providing correct and truthful information. SSOT integrated into supply chains provides greater productivity and efficiency because the data is stored in primary locations. Additionally, it also prevents the creation of mistakes and duplicates, which leads to greater and simplified control of the stored data. As the blockchain is a digital ledger with encrypted blocks of data, it provides a single source of truth for the data stored in the blockchain. Agriculture can provide SSOT with blockchain and smart contracts (Santoso, & Yulia, 2021).

Since Croatia is mainly importing meat and crops, it is important that the local consumers know and has information on what products are they consuming. Without a single source of truth, the suppliers are importing cheap and lower-quality food, for which consumers usually do not have enough information. With the blockchain implemented into the supply chain of the agricultural processes, the consumers can have specific knowledge and information about every process and production phase through which that product went through. Based on the example of a Midwestern farm in the USA, whose business is primarily focused on the distribution of eggs, it can be possible to conclude that such systems can be implemented all over Europe. Since the eggs in Europe are already marked with the code that shows the farming method and member state from where the egg is coming and the identification of the establishment. Because EU markings do not provide the packing time and date, such information could be provided through the blockchain records. The egg tracking via blockchain provides unique markings and records that can be easily referenced. Blockchain markings of products also successfully tackle the problems of forgery. The need to improve product traceability and to keep consumer demand can be the driving factors for technological changes within the specific segments of the food industry (Bumblauskas, Mann, Dugan, & Rittmer, 2020). Traceability in supply chain through blockchain allows information access under any consideration and circumstances throughout its entire life cycle, which allows the producers and consumers to follow and track the movement of the product through specific stage(s) of production, processing and distribution.

Similarly, like the application shown in Figure 10., Croatian farmers can have a platform where the data about their products can be displayed. With the scan of the QR code or bar code of the product, the producer can get information about when the food was produced and when was it distributed to the local store or farm stand. The proposed applications with a similar approach to the design like in the example of Bumblauskas, Mann, Dugan, and Rittmer (2020) do not require a complex user interface and can be easily developed. With such approaches, farmers can improve their trust with customers and can get access to more loyal customers. Having such transparent information for consumers, farmers mitigate the problems of customers' doubt about the produced food.

Figure 10. Example of UI of application for product life cycle tracking

Source: Bumblauskas, Mann, Dugan, and Rittmer (2020)

Additionally, farmers will also differentiate themselves from the rest of the producers, where customers might turn more towards the approach of supporting local food producers Horvat, Granato, Fogliano, and Luning (2019). Regarding the information gathered from the interview, one out of three farmers is in favor of the development of such an application. The farmer that is in favor of the application already has the experience of selling goods directly to the consumers through the city market, and it is possible to conclude that consumers due to the previous negative experiences have a certain degree of negative perception regarding the purchases of food on the local city markets. Other two farmers that are not in the favor of current support for the application have stated that they would not be against its future use in case the platform for such information-providing services can be provided by third-party developers.

3 PRACTICAL USE OF SMART CONTRACTS IN THE EXAMPLE OF CROATIAN FARMERS

Chapter three combines the research from academic sources with the information gathered from the primary data collection. Therefore, the subchapters 3.1. and 3.2. show practical examples in case of Croatian farmers how to achieve efficient and automized trades with brokers, and how to achieve traceability in case of the milk collection example. Additionally, the chapter covers farmers incentive towards the circular economy, and description of asset tokenization that can be implemented into the crop insurance. The chapter also covers the description of gas consumption within the smart contracts, how it can be optimized and farmers opinion regarding vulnerabilities and barriers to implementation of smart contracts and blockchain.

3.1 Description of smart contracts in goods exchange

The technology proposed in this thesis reduces the risk related to transactions and goods exchanges, and on the contrary, it empowers the relationship and trust between the transactional parties. The underlying technology of the automatic execution of smart contracts on the blockchain with the tamper-proof history of transactions helps to mitigate the transactional risk. Since farmers sell their harvest products to non-reliable brokers and are usually getting paid in cash on the spot due to reduce the risk of not getting paid in the future. The proposed technologies minimize the risks of not getting paid and allow the opportunity for getting more competitive pricing. According to the research from Kumarathunga, Calheiros, and Ginige (2022), the farmers' connection to the harvesting brokerages is usually related to the pre-establish trust where the returns are lower with low risk. Since there is no intermediary third party that overlooks such transactions between the farmer and the broker, ensuring a smooth trading relationship requires a conditional smart contract, which is going to ensure that both parties fulfill their contractual obligations in time. Especially in this example, the contract’s conditions can be written based on the historical reputation of the broker and their past executed contracts, which therefore increases the trust between the parties. (Kumarathunga, Calheiros, & Ginige, 2022).

To gather detailed insight into farmers perspective the primary data was gathered through the field research based on the semi-structured interview with the sample of three farmers, that have multiple years of experience working in on the Croatian lands. The format of the interview is based on the group triad interview, where all three participants were present at the same time, and were asked the same questions stated in the appendix of the thesis. With the formal setting of the interview, the interview followed the preplanned structure of the questions which consisted with the set of introductory, behavioral and hypothetical questions. The questions in the interview were direct, that conformed the purpose of the study, and open-ended, which did not impose any limits on the number of responses. The criteria for choosing the participats for the interview was that they have few years of experience on the market, and that they have at least 10ha of arable land and 40 livestoock. The interview was performed at the end of harvest season, during the Semptember of 2022. All three farmers wanted to keep their anonymity and did not give the consent for the interview to be recorded. The questions in the interview were formed based on the findings from previously presented literature, where the goal was to firstly inform the interviewees with the concept and characteristics of the blockchain and smart contracts, and then to further go into the specific scenarios of implementation of technologies.

Table 6. Information about interviewees

	Age	Experience in agriculture	Number of ha of arrable land	Number of livestock
Farmer 1	44	15 years	65	60
Farmer 2	54	19 years	120	90
Farmer 3	47	9 years	30	40

From the interview, all three farmers have had a negative experience with brokers that have dealt with their goods. The problems that farmers state are mainly related to late payments or even avoiding the payments in rare cases. During the end of the harvest season and when the goods have to be sold, the relationship between the brokers and Croatian farmers is not ideal. Specifically stated in the example of purchases of large amounts of agricultural goods, the brokerage companies that purchase corn and soy from the farmers would more than often manipulate the humidity of the products, stating that their product is of lower quality than when it was purchased, and farmers would often get the offered the lower price or would need to pay extra service for drying.

Furthermore, all three farmers have stated that the payments for the sold goods sometimes take up to three months, which makes it difficult to cover the correct costs and leads to more expenses. For example, the dairy companies that collect the milk from Croatian farmers on the daily basis do not collect the milk of different quality grades on a separate mechanism. Regardless of their grading system of the quality of the milk, the dairy companies collect lower quality and higher quality milk with the same truck, which would make transparency and traceability of dairy products difficult. The same dairy companies are late on their pay on the regular basis. With the information gathered from the interview, the blockchain and smart contracts could trigger automatic payments mechanisms where farms would get paid according to their daily production of the dairy products, which would eliminate late payments. Furthermore, IoT sensors within the storage containers can monitor the quality on the milk, which would inform the dairy company in which quality grade is the farmers milk. Specifically in the example of milk distribution, the data can be stored into blockchain two times per day, since the milking is usually performed in the morning and afternoon. After the conditions of the milk are read by the IoT sensors, the data can be stored into blockchain, making it immutable. By using either private or public blockchain, IoT sensors would be able to record the specific biological state of the milk and feed the information to the blocks on the automatic basis.

For instance, such data can be saved within the blockchain and can be read by the end-consumers through QR codes when they are buying the products in the store. With having such information available at disposal, the consumers are able to make more rational decisions regarding the products that they want to consume. Additionally, having such controls of the quality of milk can also have the effect of having appropriate pricing mechanisms, where the farmers that have produced milk with better quality will have greater mark up on the goods sold. With the increased transparency, the consumers can also be informed whether the milk and dairy products are coming from Croatian farms or if the products were imported, which will significantly reduce false marketing practices. Regarding the dairy company's collection of the dairy products within the same compartment, the state should impose greater controls for such procedures, because if such approach continues then the quality controls of the products do not add any value. All three farmers are in favor of reducing transactional risk and the implementation of IoT devices that can monitor the conditions of the stored goods for prevention of manipulation and more precise characteristics such as; humidity, the temperature of storage, moisture, etc. Due to the mentioned problems with the goods brokers, to minimize farmers' exposure to the risk of late payments, they would usually require the payments on the spot when the goods are delivered. The smart contract's effect on reduction of exposure to the risk of late payments would leave farmers with better availability with the cash capital which can be invested further into the business, leading to the better competitiveness on the international markets as well.

The introduction of such technologies into the farmers' relationship with the brokers that they are trading their goods with empowers the trust and relationship, and mitigates the price problems where the farmers reduce their exposure to unexpected price changes. The money received on time enables farmers to have more advanced and prospective cultivation processes, which leads to greater quality harvest seasons, as the capital can be invested in time.

3.2 Traceability of goods

As previously mentioned, one of the most critical problems in the supply chain industry is the traceability of goods, especially in safety-sensitive sectors that include food. Since consumers have a high expectations of companies to be transparent and to provide them with as much information as possible when it comes to information on food transportation and production. However, because of the fragmentation of work in the food supply chain industry, it becomes really hard to track down the goods. With the involvement of IoT devices and blockchain, those problems can be mitigated and solved (Casino et al., 2020). RFID devices on smart farms and supply chains can monitor the quality of the food throughout the food supply chain. Good and quality food is of crucial importance for the development of the world, and because of that consumers' awareness about consumed food has been on the increase. Consumers are mostly given scarce information regarding the information related to packaging environment, the temperature during transportation, the production date, etc. Providing quality information for consumers generates new economic opportunities for all stakeholders inside the supply chain (Lekha, Chakaravarthi, & Visu, 2018).

With the lack of secrecy, and the systematic provisions of products and processing information under informal and formal agremeent, transparency within the supply chain can be used as a mechanism to prevent customers from misinformation (Roth et al., 2008). Supply chain transparency is a practice of disclosing detailed and accurate information about operations and products, such as their origin and sourcing, manufacturing processes, costs, and logistics (Montecchi et al., 2021). Transparency of goods in the supply chain has been a critical element, especially for safety-sensitive food like dairy products and meat. In the example of dairy products, the farmers can track the information about the date when the milk has been collected. Regarding quality controls, the specifications and the lack of chemical substances should be noted. Through the information given to consumers, they can receive the average temperature during the storage of the milk, and when has it been prepared for orders and shipments to consumers. During transportation, the stakeholders have to monitor and provide information about the average temperature during transportation, and in case of control has not been sufficient, corrective actions should be taken (Casino et al., 2020).

Similar problems are facing the farmers and consumers in Croatia. The farmers that have been interviewed stated that their main concern is the satisfaction of the end-consumers, and providing them with high-quality products. When such a relationship is established, the local farmers can establish a good relationship with the public, displaying a positive image of their products, and enabling long-life collaboration. As mentioned, milk, which has to be collected on a daily basis, and through the control of fat, proteins, the addition of water, the presence of forbidden substances, and its microbiological state ensures that top-quality milk is distributed to the consumers. The IoT sensors enable easy control of such attributes of the milk, the dairy companies that collect the milk are required to improve their collecting procedures. As already mentioned in the sub-chapter 3.1, the dairy companies do not distingush the milk during the collection procedure, which makes hard for Croatian farmers with high-quality products to establish better relationship with the public, as their products are mixed with lower-quality ones. One of the solutions is that dairy companies either collect only milk with better microbiological state with separate trucks, or that they go through the same routes, but instead have a trucks with different and separate compartments that would enable the collection of milk with several microbiological states.

Similarly, as the example of Pagonis Sisters and Co's approach to designing a blockchain query interface, the farmers can display the product name, their quantity, description (from which cow ID it comes), global id, and the address on the blockchain. Blockchain enables the traceability of goods from being raw materials to the end-product for customers (Casino et al., 2020). All three farmers agreed that the traceability of sold goods and products plays important role in keeping their business, and that is why they are keen on the implementation of such technologies. The efficient traceability satisfies consumers by providing them with correct information about the product's life cycle, and farmers by establishing a better relationship with consumers. Even regardless of the scalability problems of blockchain, the smaller farmers in Croatia will not have problems with that, since they will not record huge amounts of data, like huge food supply chain companies. If such a system can be created, without compromising the privacy of its performance, the farmers of Croatia can benefit from its implementation. Better satisfaction of the consumers lead to a creation of positive brand image and increased demand for the products. Having that in mind, the farmers would be able to attact more consumers if smart contracts and IoT sensors would enable efficient traceability of goods throughout their life cycle. The traceability within the blockchain brings an answer to the consumers regarding the access of information that allows them to understand what and when certain processes are occuring with the purchased products. With having blockchain implemented within the explained business processes, the users will be able to differentiate domestic and imported products, knowning that the information from local farmers would be stored into the blockchain. Since the data in blockchain is immutable, it impacts the trust between the consumers and producers. Besides tracking of the products, the consumers can be provided with the information when the certain food has been produced, and what are their nutritive values.

3.3 Description of how smart contracts can achieve a circular economy

Since the circular economy has been widely promoted by the EU, different nations, and governments across the globe, Croatia should not overlook that, but focus on the promotion of environmental and sustainable development. The European Commission has estimated that with the use of a circular economy, the EU can create around 600 billion euros annually of economic gains that can be invested into the EU manufacturing sector alone. The circular economy has been highly promoted because of its approach to encouraging economic development through preserving a sustainable environment. The introduction of the circular economy into agriculture is a concept that can mitigate the negative environmental impacts on the environment and stimulate new opportunities in business, while at the same time promoting a green and sustainable environment and waste reduction. It focuses on using a product or resource that has been extracted from nature to be used more than once, which increases the value over time, saves costs for the business and also reduces emissions, and waste. The benefits of the circular economy through the input and output values and resources are that the losses are reduced, reduced waste management costs, reduced emission control costs, new markets are found for the value in resources and it promotes the sharing economy (Korhonen, Honkasalo, & Seppälä, 2018).

Due to the reason that global demand depends on agriculture, it should focus on practicing the circular economy, since within Europe, around 700 million tonnes of agrifood waste has been generated each year, which with increasing population is only going to rapidly increase. The increasing waste in agriculture has been associated with global warming and temperature changes which results in a reduction in crop yields and a rapid increase of pests and weeds on agricultural lands. The mentioned agricultural problems can be tackled through the development of a circular economy, where the focus is on the usage of innovative technologies that help to utilize waste. Specifically, in the context of Croatia, they produce around 6 million tons of waste per year (World Bank Group, 2022). Since the circular economy is different than traditional linear production models, the current family farms in Croatia will have to be adjusted to the different business processes. Because such change requires data collection and sharing, blockchain could come useful in the circular economy. Transition and changes are also required at the supply chain levels, not only in the production phases. The focus has to be put on re-evaluation and reshaping the current and existing agricultural processes and production systems, which results in lower waste. According to the AgroCycle CE system, the waste produced in agriculture can be used to produce nutrients that will fuel raw material inputs, energy, and heating (Toop et al., 2017).

With the decentralization of the supply chain in agriculture via blockchain technologies it is easier to introduce the circular economy. The basis of a circular supply chain via blockchain is based on the “Make-Use-Recycle” model, where the purpose is that the economy becomes self-sufficient. As mentioned in the sub-chapter “Traceability of goods” the usefulness of blockchain lies in its easiness of information-sharing which helps to trace the products from raw materials to recycling. The significant advantage of such supply chain model over the traditional models is that with high confidence, the information about products can be provided at any time to the users of information and final consumers, which can be achieved by storing data and information about transactions in the blockchain. Additionally, the model becomes more efficient and automized because of the use of smart contracts that manage the supply chain processes instead of the multi-agent systems which significantly reduces costs, time, and errors (Casado-Vara, Prieto, la Prieta, & Corchado, 2018). When referring to Croatian farmers, as a smaller-scale agricaltural producers, they have already started incorporating some aspects of the circular economy. Circular agriculture can be seen in the form of arable lands that are based on eco-production that excludes the use of any pesticides and is highly promoted and supported by funds from the EU. Such an approach is mainly supported in the orchards and fields where different sorts of nuts and clovers are planted. It has been estimated that in food production the circular economy has the ability to reduce the usage of chemical fertilizers by 80% in Europe (Sv. Helgason, Iversen, & Julca, 2021).

The circular economy is based on many contracts among the existing stakeholders which could be compensated by the implementation of smart contracts. Because of blockchain’s credibility of being transparent and secure in the information exchange, it significantly helps in the digital transition towards the realization of the circular economy. The approach to a circular economy with the blockchain for its underlying infrastructure improves the stakeholder interactions and allows them to make more clear data-driven decisions across the network. As previously mentioned, smart contracts could be used for the sharing of information, transfer of payments, financial payments, monitoring of payments, etc. Smart contracts in the circular economy can enable different stakeholders to work according to the pre-defined conditions specified in the contract. The automatic execution of smart contracts brings better engagement in the circular economy. On the other hand, because of blockchain's transparency, it brings higher responsibility to the stakeholders of the circular economy during financial transactions (Kumar & Chopra, 2022).

According to the information from the interview, all three farmers have experience with the eco-production supported by the EU. In the majority, they have removed the use of pesticides in the clover fields. Every farmer from the interview has the same experience with eco-production. While they support the positive impacts of the eco-production of agricultural goods, they mainly note the problems that they have to deal with. Mainly, the fields have problems with different weed intruders that affect the quality of clover that is used for feeding of the animals on the farm. The interviewed farmers are familiar with climate change and their ecological impact and are looking forward to continuing to practice more ecological approaches to their production if they can be supported through it by the EU. Regarding the efficient allocation of waste, they do not have proper landfills at their disposal, which have not been provided by their municipal units. With more ecological approaches supported by the state and EU, the Croatian farmers would be able to create positive impact both on climate change and their competitiveness. With more ecological ways of creating food, the Croatian farmers would be able to provide better-quality products on the market, for which the consumers are ready to spend more. With the better informability of the consumer and as the relationship between the producer and consumers gets stronger, the consumers are willing to spend more for the products for which they are sure that the ecological procedures are followed, and that the products were developed without any pesticiders or chemicals. Through different monetary and technological developments, the state should invest towards the digitalization of Croatian farms and to shift away from traditional farming approaches.

3.4 Description of smart contracts in crop insurance through asset tokenization

Tokenization of assets that are on the blockchain can be described as leverage of underlying technology to securitize assets that are either traded or non-traded. The reasons why to pursue tokenization are smaller costs, more efficient risk management, and improved liquidity. The tokenization of real-world assets in blockchain technology has been on the increase and has attracted the industry's attention. In simple terms, tokenization can be described as a process that is used to transform rights or units of asset ownership into digital tokens that are based on blockchain. Tokenization is usually applied to bonds and equities, precious metals, intellectual property, or real estate.

Through the process of tokenization of certain assets, liquidity and transparency are improved. Specifically, in the case of Croatian farmers, the chapter will describe asset tokenization in the context of crop insurance, with which the farmers are dealt on the yearly basis. Farmers might pursue and benefit from asset tokenization because of the broader geographic reach since the public blockchains do not have external barriers and are decentralized. More importantly, tokenization upgrades the infrastructure that is supporting fundraising and insurance and reduces settlement times, which significantly reduces slow transaction times by the insurance companies (BNY Mellon, 2019).

Tarhini (2021) explains how asset tokenization can improve general and crop insurance focusing on agriculture, and how to take advantage of fundraising without the intermediaries under contractual and standardized regulatory control. The payments for coverages in insurance are usually associated with usually long and frustrating claim cycles. Depending on the specific insurance policy that the insurer is having, asset tokenization through smart contracts simplifies complex structures and processes of diverse parameters and different variables that usually are not simply executed without delaying any time. By reducing the transaction cost the contracts will also reduce the time taken to perform the transactions obliged by the contract, which minimizes the exposure to the exchange rate risk and the exposure to the interest rates. Since smart contracts are operated on the blockchain and executed by the conditions in the code, the standardization in finance and accounting of such contracts is significantly increased. The standard formats of insurance contracts are easier to interpret are easier to follow. The process of tokenization can be described in the following steps:

1. Step 1 – The crops of a farmer can be recreated in the form of asset splits which allows them to be tradeable, easier to move, and fungible if needed. The process of digitization in the next steps of tokenization is dependent on how the asset is represented. Therefore, farmers can use different assets as tokens, such as; crops, machinery, land, and farming equipment can be turned into tradable tokenized assets that can be used to mitigate the expenses of depreciation or in a way to recover costs

2. Step 2 – The meaning of conversion of tokens to be digitally represented for each token means that such tokens have to be backed by certain assets, which can be in a form of pooled insurance services or crops for farmers, or in some specific cases it can be insured through a future investment and in a form of micro-payments that can be used for support of small farmers that can have access to DeFi through smart contracts and blockchain

3. Step 3 – In step 3, it is possible to issue the token on a blockchain, either on a public or private one. Tokens that are issued on blockchain have their unique addresses and unique code that is used for identification. Code and address allow tokens to be immutable and tradeable on different trading exchanges

4. Step 4 – With peer-to-peer trading in step 4, the tokens are available to be traded which adds value for both farmers and investors. Tradable tokens can lead to an increase in the value of the original underlying asset of the token over the time

The smart contract to insure the assets needs to have the following characteristics: pre-defined contract, event trigger, execute and value transfer, and settlement. In pre-defined contracts, both parties have to agree to the terms of the contract, which is coded into smart contracts and has immutable property. The code needs to include all the terms and conditions, limitations, penalties, and other legal obligations of both parties. The event that triggers the execution of the contract is also hard-coded into the smart contract. The events can get triggered by the information and data received from the network, IoT sensors or RFIDs, and other smart devices that collect data. Because smart contracts are automatic, they get executed based on the pre-agreed terms in the contract, and it gets executed without any reversible options. Settlement happens instantly and efficiently and can be paid in stablecoins to avoid price fluctuations, through which the traditional banks are avoided, and transaction times are reduced. The actors in asset tokenization in insurance are:

- Insurance company – Provider of the insurance that is securing the pool of funds when and if the contracts are executed

- Farmer – Individual that requests the service from the insurance company and expects compensation if the smart contract is executed

- Service provider – Provider of the technology on which the smart contracts are coded – blockchain

- Weather data provider – Provider of data that relates to the weather, which can be coded into smart contracts

For instance, crop insurance can be based on the damages that have occurred due to sudden changes in the weather or climate change over the years. Crops can also be insured against the soil and irrigation difficulties that can be caused by natural disasters. Additionally, the insurance can also be implemented in regular farming activities such as the damage of machinery or tools, damage to post-harvest crops, loss of crops due to plant pests, and organic remedies (Tarhini, 2021). Smart contracts can particularly be useful in the bookkeeping of inventory, logistics, and the negotiations between the stakeholders that are related to moving large quantities of food. Particularly for the programming language Solidity in EVM, the developers have introduced a cosine similarity metric in EVM. The cosine similarity metric can be useful in checking the weather and different factors that can impact and possibly change the crop quality in the fields, which can help create the basis for new negotiations in the contracts (Voutos, Drakopoulos, & Mylonas, 2019).

With the data gathered from the interview, the farmers stated that they were never paid according to the insurace that insured them against the possible weather damages. It was possible to conclude that farmers usually do not have favorable conditions when they are trying to insure their crops, which more than often makes it more selective of which fields would be insured throughout the year against the possible weather impacts. Because of that, all three farmers showed interest in the implementation of smart contracts through the tokenization of assets if it would give them fair conditions of insurance contracts. In case of the weather disasters, they have stated that data should be provided by the weather data provider and it should be compared with the damages within the field, which could give a more detailed analysis of the occurred damages. Instead of approximate decisions of how much damage was done to the fields, the insurace companies would be able to gather the information from different weather providers or IoT sensors to obtain exact damages on the field, in case of a draught or a hail. With having such insurance contracts written within the smart contracts, the farmers are able to get exact insurance claims, with which they are able to re-invest into the damaged crops, and with such approaches, they would be able to maintain the expected seasional outputs. Knowing that their insurance is not a waste of capital, farmers would be more in favor of greater insurance of their fields and equipment, which would help them to achieve relatively stable outputs throughout the year.

3.5 Gas fees optimization, and how to minimize the costs with the use of smart contracts

The amount of dApps on distributed ledger technology has been forecasted to grow, with the expected value of around USD 57,641.3 million by the end of 2025. DApps are built on blockchain and are incorporated inside smart contracts. The most popular blockchain platform for providing the environment for smart contracts and code is Ethereum, where the smart contracts are developed with the Solidity programming language and are compiled into bytecodes which are going to be executed on the EVM. Since the smart contracts that are executed and run on blockchain bear the cost of execution because of the block mining that creates the chains, it can become quite pricy. The execution fee that compensates the computing resources on Ethereum virtual network is called the gas and is paid in the Ether. This means that, if the smart contracts within the dApps are not optimized, it can lead to unnecessary costs and gas leaks, which can result in money loss and expensive transactions. Scaling in this example could lead to significant financial losses in the business if the gas in the smart contract is not managed properly and if they are not optimized (Di Sorbo, Laudanna, Vacca, Visaggio, & Canfora, 2022).

Ethereum blockchain uses the "transaction" terminology to explain and refer to the data that stores a specific message and which is sent to an external address/account. The transactions within the Ethereum blockchain contains start gas and gas price (determined by the miners), which are required to start the execution of the transaction. Start gas shows the limit and the gas price shows the fee required to pay to the miners. For gas optimization, the developers can use Gasol, Gascheker, or Hasper tools. For instance, Gasol is used to helping to detect the gas optimization approaches within the Solidity, while Gascheker is the tool that can automatically identify the gas-inefficient code within the smart contract (Nageshawar, Chourey, & Shrivastava, 2021). The costs in the smart contracts depend on the amount of code written inside it and its size, and by the number of operations that the contract needs to execute. The reason that every operation and size of the contract are determined by the amount of gas that has to be paid, it requires the code to be written in an efficient and cost-friendly manner. With the use of Gasol, the users, and developers can reduce the consumption of gas for transactions and make sure that the contract will not be impacted by the out-of-gas vulnerabilities. Users have the option to choose between the different optimization modes for the reduction of gas consumption which is associated with the usage of storage only.

According to Gao et al. (2021), the authors have developed a toolkit named sOptimize whose goal is to reduce the consumption of gas for smart contracts written in Solidity language by looking for redundant run-time checks and removing them (those checks are usually introduced because of the security concerns). sOptimize toolkit also uses the technique of static analysis and loop in-variant techniques for verification if a certain code block is unnecessary or not before optimization of the contract is applied. The purpose of sOptimize is to find the most optimal usage of gas based on the elimination and detection of code that is redundant, i.e., redundant nodes, partial-redundant nodes, or dead nodes on the proposition of security. Around 43.3% of test subjects are shown to be potential that can be optimized and where the size of the written contract can be reduced by 2.0% in terms of bytes on average, which approximately can save around 29,900 units of gas while being in the deployment and 328 units of gas for transactions that are relevant with nodes when they are in the run-time environment. In such cases, the gas is reduced as high as up to 25,575 units while the contract is in deployment and 954,201 units in transactions.

Regarding the farmer’s perspective on the implementation of blockchain and smart contracts, they are not willing to implement such technologies if they will pose new costs. Additionally, all three farmers have stated that they are not familiar with the terminology of such technologies, and they do not understand their concepts. Since their businesses bear a lot of unpredictable costs, they are not keen on having technology that they cannot control nor control its costs. Two out of three farmers have mentioned that if such projects are supported by the government and other farmers, they would be willing to participate in the trial periods for tests but would need to go through some forms of education to inform themselves better. Regardless of the new imposed costs, the state should encourage the change of existing traditional approaches, because with the automatization of several farming and bureaucratic processes, the Croatian farmers are able to shift to improve business processes. The farm architecture with the blockchain, smart contracts, and IoT brings new ways of making more data-informed decisions through which are farmers able to greatly contribute to consumer satisfaction. Additionally, the farmers would be able to get insight into certain statistical data on their crops and the state of the fields, which would bring them a new perspective on the possible improvements and changes on the existing conditions that must be changed. With the support of state and local authorities, the state can potentially fund the educational trainings where the farms could get informed more about the blockchain-based solutions within the agricultural sector.

3.6 Vulnerabilities of smart contracts and blockchain

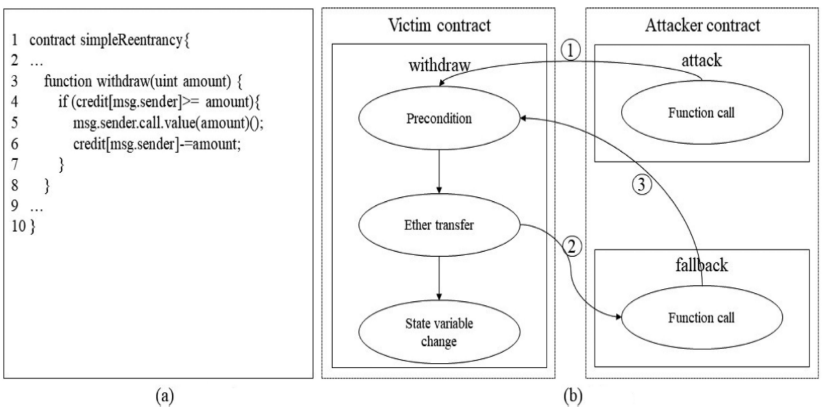
Security on the internet and online purchases still remains one of the top concerns of users, as many users are still experiencing trouble understanding the importance of protecting personal data. Especially in Ethereum and in smart contracts, billions of dollars have been deployed, which at the same time increases the potential of new investors and the interest of the hackers to take advantage of it. Since smart contracts are still fairly new technology, they are prone to errors in the code during the deployment. Because the contracts are immutable, they cannot be changed once they are deployed, instead, they have to be disabled and deployed again after the change has been made. Humans are typing smart contracts, which are still prone to include some errors, because of the lack of developers and experience in the blockchain environment. Due to smart contracts being prone to errors, millions of dollars have been lost, and usually, it is hard to almost impossible to recover them. To reduce the errors in smart contracts, the developers are undergoing a static and dynamic analysis of contracts before they are deployed. For easier recognition of threats, developers in the blockchain environment give each vulnerability a title and a description of their characteristics. Additionally, the relationship with CEW (Common Weakness Enumeration) is described, as the remediation procedure for such threats. For future context and to avoid such threats, they also provide examples of smart contracts with vulnerabilities and their fixed versions, where the other users can check the patterns and follow the guidelines so that they develop and deploy the contracts without any bugs and errors.

According to the vulnerabilities in Ali, Abideen, and Ullah (2021), their tool SESCon is able to detect the vulnerabilities in the smart contract patterns and therefore is able to provide vulnerability detection with very high accuracy. SESCon's pattern recognition is based on the taint analysis that uses statistical analysis of the smart contract's source code that is written in Solidity. It also provides an underlying foundation for standardization that can be used for reporting and detection purposes of vulnerabilities. Based on the real and deployed contracts, the SESCon tool has managed to show existing vulnerabilities in the majority of the smart contracts (around 90%).

As previously mentioned, the implementation of smart contracts is most popular on the EVM platform, which is based on the basic structural elements (similar to classes in OOP), functions, and variables. When the contracts are deployed, they are usually considered as “law” and cannot be changed anymore. Considering the “law” characteristic in a contract, every behavior and circumstance should be defined in a contract. Regarding the technicalities of the contract, the fallback function can be executed by being triggered to handle some uncommon cases such as (1) when its own contract is being called with the function name that is unknown, or (2) when the plain Ether is delivered to the contract (i.e., Ethereum currency) without any context or information to the data. Regardless of the approach, if not protected against such mechanisms, the users can face unpredictable reentrancy vulnerabilities that usually result in high economic losses (Xue et al., 2020).

To avoid and minimize the false-positive results from the analysis, (Li, Pan, & Hu, 2022) propose the ReDefender analysis tool which is based on dynamic analysis. The proposed tool is based on two-phase verification methods through which the developers are able to determine and spot whether there are vulnerabilities within the smart contracts. Reentrancy is considered to be the most well-known vulnerability in smart contracts. The previous attacks show how reentrancy can be dangerous and costly for DeFi protocols, for example, the DAO attack which happened in 2016 suffered more than 60 million dollars in losses. Due to the low rates of detecting such vulnerabilities in smart contracts, the tools that are being used usually provide undesirable false-positive results and false negatives and are not successful in detecting them (Li, Pan, & Hu, 2022). The reentrancy procedure can be explained as the process where the contract makes the external call to another contract, which ends up making the call back to the original one. Reentrancy vulnerability has two specific characteristics. The first characteristic is the unexpected reentrancy procedure to the same contract during one single transaction, while the other characteristic contains malicious behavior after reentrancy occurs (e.g. unexpected modification of global variables in smart contracts or stealing funds).

Figure 11. Illustration of reentrancy procedure



Source: Li, Pan, and Hu (2022)

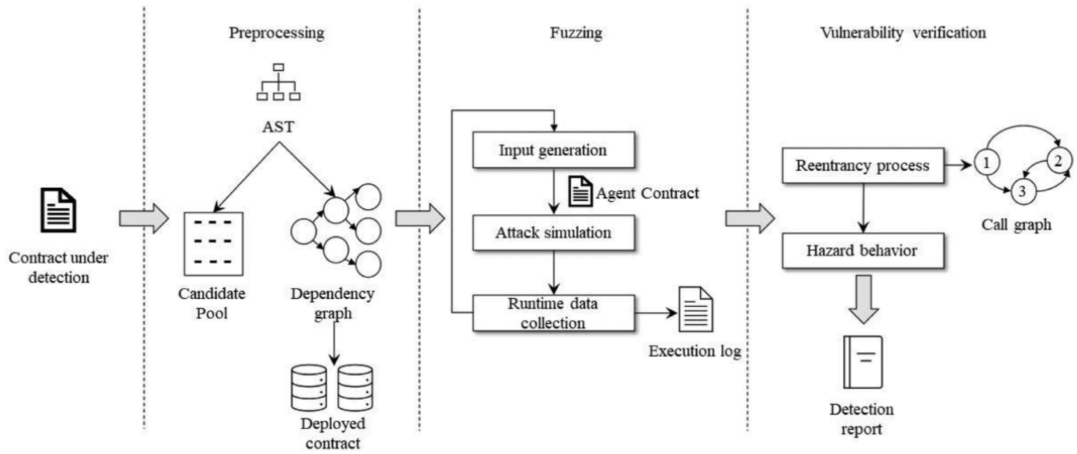
Based on the tool proposed by Li, Pan, and Hu (2022), figure 12. shows the stages for detection of reentrancy vulnerabilities;

1. Preprocessing – The issue that preprocessing solves is that it analyzes and marks which functions of source code can be affected and exploited by the attack and helps to realize potential reentrancy.

2. Fuzzing – is a cyclical process testing the contract with fuzzing inputs to create the execution logs for future analysis. The purpose of fuzzing is to create the simulation of a reentrancy attack until exceeding the timeout.

3. Vulnerability verification – a phase that identifies if the reentrancy that occurred was malicious

Figure 12. Detection process for reentrancy vulnerability



Source: Li, Pan, and Hu (2022)

The security within the blockchain technologies can be limited since Blockchain is not able to control the data that might require privacy for military purposes or data that is classified as corporate business secrets. Furthermore, the other problem that Blockchain is faced with is that it cannot execute other data processing apart from storage, like deletion and modification**.** Due to such characteristics, blockchain requires separate protections for security precautions to be implemented that can be able to protect the rest of the data processing that blockchain cannot perform. For that reason, it is not safe to assume that Blockchain can be secure as an entire system environment, making it invulnerable to cyberattacks from outside. According to Manoj (2020), they argue that Blockchain does not have superior characteristics in comparison to any other traditional centralized databases except decentralization. To emphasize blockchain's security, the users have to perform threat modeling, which is usually conducted by organizations to have a better approach to cyberattack threats and to have a systematic approach where the organizations are able to identify any potential issues of the security in advance. Generally, the threats usually expose the systems to different cyberattacks that are trying to attempt to steal the data during its transmission, intercept the communication between the channels for potential theft, or restrict the access of the users across the channels. For better prevention of such attacks, threat modeling is useful in discovering the cyber threat of data tampering, which is an act in which the attacker changes user-submitted data into malicious and harmful data. Normally, data tampering will expose a system subjected to data manipulation that will cause accidental or incorrect system execution, which can include the following: tampering of components, corruption or manipulation of data, or ledger malleability which will cause corruptions within the Blockchain protocol.

With the cyber threat called denial of service, an attacker can interrupt the authorized user's access to a specific computer network with malicious intent. The attacker is prone to expose the components accessible on the public internet to operation halts, corruption of data, or system malfunction. With the threat of data disclosure, the system component is designed in a way that it can store or process sensitive data like hot/cold wallet or offline/online storage of funds. Data disclosure will usually include risks such as theft or loss of data.

Four security domains of blockchain system presented by Manoj (2020):

1. Platform domain (D-1) – a platform that is created out of different blockchain elements and participants, such as nodes and public ledgers. Because of different consensus mechanisms that are required for the validation of data and decisions if the blocks will be added, nodes might be considered as one of the most important components within any Blockchain system. Ledgers can be represented as the data that is stored in the system across each node. Regarding the security reviews of the domain (D-1), it should primarily focus on communication for data processing, synchronization, and redundancy.

2. Front-end domain (D-2) – Front-end customer-facing server and application such as web server developed to maintain digital wallets or cryptocurrency exchanges for crypto storage. This is similar to the usual and prevalent centralized IT system environment.

3. A decentralized application domain (D-3) – applications that are developed and run on Blockchain. The applications that are built on the blockchain are shared across the entire network of the environment of the Blockchain system, which is different than traditional computer applications. Therefore, the evaluation of security approaches in this domain must be examined from the aspects of static (source code-based) and dynamic (running and execution cases) aspects.

4. End-points domain (D-4) – Domain that can include computers, terminals, or mobile devices through which users can communicate with a Blockchain network which

would allow them to access it for usage and service purposes. Data is the most vulnerable in this data flow chain. This makes the D-4 domain the optimum target for cyber-attacks, so it is essential that this domain has effective protection against the previously mentioned attacks.

Since the farmers have little technological backgrounds and knowledge about the hacking attacks and potential security vulnerabilities, the best approach for development of blockchain-based architecture would be through the companies focused on the creation of blockchain-based services. The Croatian state can ensure the projects with the third-party developing companies with which the farms could have a business collaboration. With having experienced companies creating the described architecture, the farms have increased security and minimize the risk of their data being compromised. By reducing such risks, the Croatian farmers are ensured to have more efficient business processes, allowing them to put more focus into how to maximize the output of their crops.

3.7 Barriers to implementation of blockchain in SCM

According to the survey results performed by Petersen, Hackius, and von See (2018), the goal was to see the experts evaluate the relevance of blockchain within the supply chain and logistics industry. The survey analyzed 152 participants, and the most usual answer regarding the barriers to the implementation of blockchain was related to regulatory problems, third parties joining forces, lack of technological maturity, lack of acceptance in the industry, and concerns about data security issues. The information gathered from the survey showed similar results as gathered from the review of articles explained below. The blockchain can be used in SCM due to its extraordinary ability to record, share and transmit data stored in the blocks. Blockchain affects the coordination in the supply chain, because all the elements within the chain have similar forms and characteristics, and they cannot be erased or modified. Because of blockchain's good characteristics, it is easy to overlook the present barriers to the implementation of blockchain into SCM.

According to Sabbagh (2021) the challenges with which the implementation of blockchain in the supply chain can be divided into four classes:

- Specialized and security hindrances
- Monetary and HR boundaries
- Hierarchical and singular obstructions
- Social, natural, and social obstructions

In specialized and security barriers challenges, the focus is put on technical maturity shortage, security of information, usability, unpredictability, cooperation, forking, and scalability and execution. Because the blockchain is still in the early development phases, the innovation and people who have encountered these problems in blockchain are still adjusting to innovative changes. The blockchain can be prone to bugs coming from digital experts because of a lack of innovative approaches, and if these imperfections are exploited, it usually leads to monetary losses. For ensuring strong *information security* in the blockchain, it is required to use encryption. Encryption can be exposed to risk with quantum figuring, where computers work in 1-second and 0-second language. Such computers can achieve a third case where this triple information is stored in the structure called qubits. For instance, these computers can perform a significant amount of activities a large number of times, and eventually, they can break the security and create blockchain innovation more vulnerable in the coming years. Since such frameworks are fairly new and a lot of people are not familiar with the terminology, they become really hard to use, which leads to problems with usability.

In *multifaceted nature,* the blockchain frameworks are hard to be distinct from existing frameworks, and the current frameworks might not be adequate for existing problems of the business. In *cooperation,* the developers need to find a way where the existing frameworks need to work together with blockchain or to fulfill the existing processes, that cannot be improved without the implementation of blockchain. It is important that similar blockchains and similar frameworks are used together. The updates of the existing blockchain are called *forking*, where usually the underlying blockchain improves its abilities and execution. Forking can lead to a disturbance in the blockchain system if one of the clients will not transfer to the forked version of the blockchain, where they will not be able to access information on the new blockchain. The performance of blockchain is significantly lower than the current frameworks used in everyday business, which poses *execution and scalability* barriers. The blockchain performance does not favor the large-volume works and high-speed exchange of data.

In money-related and HR barriers, the users and developers have faced IT staff deficiency, high venture costs, absence of research and development, absence of technology infrastructure, and absence of financing for blockchain innovation. The blockchain development environment lacks a huge number of adequate number of IT staff, which makes it difficult to focus on the development of concentrated blockchains that can be used in the combination with the supply chain. The blockchain cannot be utilized properly due to *IT staff deficiency*. Blockchain development is associated with *high venture costs*, which makes new developments expensive, since blockchain projects are mainly in the experimentation phases, they acquire a lot of costs. *The lack of research and development* and the *absence of technological infrastructure* is a significant obstacle that drives organizations away from implementing blockchain into their frameworks. Blockchain innovations are also faced with the problem of *financing* since the government is not favored to finance such projects and encourage their development.

Organizational and singular obstructions bear the barriers of solid progressive structure and administration, precise managerial control, data sharing barriers, and individuals' mindsets must change. *Progressive structure and administration* barriers explain the fear of losing bureaucratic characteristics through the individuals who work there, which mainly oppose such innovations. Companies with strong administrative structures and approaches will have significant problems while moving to the blockchain due to the existing *managerial controls*. The companies that have implemented blockchain might struggle to *share the data* with other businesses that are not a part of their new frameworks that are built on blockchain. To be the drivers of the change, the companies have to change the mindsets of the workforce and individuals so that they will look forward to the changes, instead of being opposed to them. Such changes disturb the existing work processes in the companies and are usually not welcomed.

The last class by Sabbagh (2021) is social and natural obstructions, where we have data sharing (natural and social angles) and lost assets barriers, where the data sharing in social and ecological viewpoints is tackled, and how different people are reacting to the changes. Since blockchain requires a lot of electrical power to perform its main core functions such as computational and mathematical formulas, through mining, it leads to lost assets, which can be invested somewhere else.

With the process of systematic literature network analysis (SLNA) that is composed of two methods; citation network analysis (CNA) and systematic literature review (SLR), the authors have conducted a throughout the research to perform a high-quality study to analyze the potential barriers of blockchain implementation in agri-food SCM. With the detailed analysis to answer the question of possible challenges that might affect the implementation of blockchain, they have come up with similar answers (Sabbagh, 2021). The main challenges that (Zhao et al., 2019) points out are related to the ability of scalability and storage, privacy leaks, problems of lack of IT staff, regulation issues, and unpredictable and high costs (Zhao et al., 2019).

To ensure the analysis of barriers to entry, Yadav, Singh, Raut, and Govindarajan (2020) which is based on the analysis of the adaptation of blockchain technology in the Indian agricultural supply chain, the results were similar and have shown the same barriers. The barriers are related to the low and lack of government regulations, where the authors state that most countries are not willing and are not ready to implement blockchain practices. Additionally, due to the approach of proof-of-work, the blockchain is associated with huge resource consumption and high energy costs, which require sufficient infrastructure, in which most businesses are not willing to invest the right amount of capital. Since there is no universal standardization, most blockchains fail to operate in coexistence, and security and privacy issues remain one of the biggest concerns. For the processing of big amounts of data and the need to process data at a fast pace, the authors have once again noted the problems of scalability and the speed of transactions. Additionally, the authors have also found that the middleman in the agricultural supply chain resists the implementation of blockchain, because of cultural changes, which therefore can be applied to the example of Croatian farmers as well. The stakeholders in the farms are usually not tech-savvy, and they would face a lot of technical problems when using such technologies (Yadav, Singh, Raut, & Govindarajan, 2020).

The data collected from the interview complements the data obtained from the journals. All three farmers have mentioned the existing and regulatory problems related to the bureaucracy in Croatia. Bureaucracy is in desperate need of automatization, and it delays processes on a frequent basis. From getting the documentation and communicating with government officials, all farms have experienced delays in documentation processing and communication. In case blockchain can solve such issues, all three farmers would be in favor of its implementation. Furthermore, because of the lack of acceptance of blockchain and smart contracts in the industry, they would not be willing to accept it as well. The farmers are specific that they would prefer not to be the industry leaders by implementing such technologies, but instead would prefer to catch onto the existing trend in case it gets implemented. On the other hand, they have raised concerns about the safety of their private data, especially when talking about information that could contain information regarding transactions. Two farmers have mentioned that they are not tech-savvy, and do not use computers on the regular basis, so they would prefer to avoid getting exposed to more risks.

Regardless of not being tech-savvy, the farmers are not familiar with blockchain and smart contract technologies and have a lack of knowledge regarding their technicalities. The only information previously obtain was through web portals that mentioned Bitcoin during their high upward price movements, and not a single farmer was familiar that such technologies can be used for different processes within the supply chain industry and in smart farming. One farmer has mentioned that he would be in favor of the adoption of blockchain if it can make their transactions with brokers and other partners easier, more efficient, and less costly. As the Croatian local authorities ensure the education and training about the efficient use of ecological production on the yearly basis, they can also focus on making farmers more informed and educated on the existing technological trends that would allow them to digitalize existing business processes. With having such approach to the problem, the Croatian government could imapact the farmer's negative opinion towards the technological changes while making them more technologicaly savy. With increased knowledge about blockchain, smart contracts and IoT solutions, potential existing blockchain-based solutions can be a leading example of technological solutions that bring transparency and automatization to the agricultural industry. With the information obtained through the interview, the farmers would listen to the blockchain educations if that can help them improve their existing business processes.

3.8 Recommendations for future research

The recommendation for the further research is to focus on the of specific scenarios of how the proposed technologies such as blockchain and smart contracts can be implemented in the digitalized agrifood business processes. The further research can be applied to specific business processes in agriculture that can be automized or digitalized with proposed technologies. Additionally, it is important to make further research about the barriers regarding the implementation of such technologies and how to possibly mitigate them. To familiarize the Croatian farmers with the purpose of such technologies and their potential, it is important to focus on improving their digital knowledge and to get them familiar with the technological knowledge. Croatian farmers could potentially get more familiar with such technologies through the classes organised by the Croatian government, similar to the existing classes that they have for best-farming practices such as use of pesticides etc. Similarly on the example of the Netherlands, the pilot projects can be supported by different Ministries of Croatia that could help in the planning and realization of such projects.

Additionally, to reduce the negative implications from such technologies, it is highly advised to research into their research and development and to invest into the innovation of the projects that could expand the field of applicability of proposed technologies and mitigate problems such as security, new arising costs, and energy consumption. With the maturity of the industry, it will certainly become more resistant to the hacking attacks such as reentrancy and DDOS attacks, which would eventually create the implementation of such technologies more attractive in a lot of industries. To increase the innovation of blockchain technologies, it is advised to continue making new research into what fields can it be implemented and how to possibly extend the context in which it could be applied.

CONCLUSION

From the information obtained from the research, it is possible to conclude that blockchain and smart contracts have wide adaptability, predominately in industries such as finance, health care, and supply-chains. Considering the advantages of the proposed technologies in the thesis, it implies that they can be incorporated into various business processes that can lead to improvement of operational performance in mentioned industries. Because of the characteristics such as immutability and transparency, blockchain can bring digitalization to the supply chain. With the increasing demand from consumers for more transparent information, blockchain serves as a perfect underlying infrastructure for the development of new and modern supply chain architecture. On the other hand, the improper implementation of blockchain can be a problem because of the increasing energy costs, hacker attacks, and security issues.As a main subject of the thesis, Croatian farmers had dealt with many problems within their existing supply chains and agricultural approaches, which makes them consider applying such technologies in their day-to-day operations. Despite the favorable market conditions and amount of disposable arable land, Croatian farming has been on a decreasing trend, and each year there is a smaller number of registered businesses followed by the increasing trend of the aging population.

Blockchain's infrastructure in smart farms can require the application of IoT devices, RFID tags, and smart contracts. In combination, such technologies can bring automatization and data-driven decisions in several business processes. For instance, in the case of farmers, it reduces transaction times and improves their relationship with brokers within the chain. Most importantly, farmers are able to provide a single point of truth to the consumers with detailed information regarding their products, such as date of production, date of expiry, the average temperature during distribution, etc.

Due to the predefined conditions that get triggered when the conditions are met, smart contracts mitigate the problems of delayed payments and can automize insurance payments in agriculture. Since the technology is still in its early stages, it might lead to high gas prices in case contracts have to deal with huge amounts of data, meaning that such technologies have a problem with scalability. Due to the reason that industry still early, there is a lack of competent IT staff that can develop secure systems and a lack of research and development projects for such technological infrastructures. The Croatian farmers that were interviewed for the thesis were not familiar with the technologies, and have mixed opinions regarding their implementation. In case of high costs of technologies, the farmers would not be in favor of implementation but would be willing to automate their daily processes and to more transparent information to consumers. Nevertheless, blockchain and smart contracts are the perfect set of technologies that can improve business processes in food supply chains. Better information sharing and transparency would increase trust between local farmers and consumers, which would shift demand more toward the support of the local business.

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APPENDICES

APPENDIX 1: POVZETEK (SUMMARY IN SLOVENE LANGUAGE)

Iz informacij, pridobljenih z raziskavo, je mogoče sklepati, da so tehnologija veriženja blokov in pametne pogodbe široko prilagodljive, predvsem za panoge, kot so finance, zdravstvo in oskrba. Upoštevajoč prednosti predlaganih tehnologij v magistrskem delu, to pomeni, da jih je mogoče vključiti v različne poslovne procese, ki lahko privedejo do izboljšanja operativne uspešnosti v omenjenih panogah. Še posebej zaradi lastnosti, kot sta nespremenljivost in preglednost, lahko veriženje blokov vnese digitalizacijo v dobavno verigo. Zaradi naraščajočega povpraševanja potrošnikov po preglednejših informacijah tehnologija veriženja blokov služi kot popolna osnovna infrastruktura za razvoj nove in sodobne strukture dobavne verige. Po drugi strani pa lahko nepravilna implementacija veriženja blokov predstavlja težavo zaradi naraščajočih stroškov energije, hekerskih napadov in varnostnih težav.

Glavna tema magistrskega dela so hrvaški kmetje, ki so se ukvarjali s številnimi težavami v svojih obstoječih dobavnih verigah in pristopih k kmetijstvu, zaradi česar razmišljajo o uporabi takšnih tehnologij v svojem vsakodnevnem poslovanju. Navkljub ugodnim tržnim razmeram in razpoložljivi količini obdelovalnih površin pa je hrvaško kmetijstvo v trendu upadanja, vsako leto se število registriranih subjektov zmanjšuje, sledi pa mu tudi trend naraščanja staranja prebivalstva.

Infrastruktura veriženja blokov na pametnih kmetijah lahko zahteva uporabo naprav IoT, oznak RFID in pametnih pogodb. S kombinacijo takšnih tehnologij le-te lahko prinašajo avtomatizacijo in odločitve, temelječe na podatkih, v številne poslovne procese. Pri kmetih, na primer, to lahko skrajša čas transakcij in izboljša njihov odnos s posredniki v verigi. Najpomembnejše pa je, da lahko kmetje potrošnikom zagotovijo enotno točko resnice s podrobnimi informacijami o svojih proizvodih, kot so datum proizvodnje, rok uporabnosti, povprečna temperatura med distribucijo itd.

Zaradi vnaprej določenih pogojev, ki se sprožijo, ko so izpolnjeni pogoji, pametne pogodbe blažijo težave z zamiki plačil in lahko avtomatizirajo izplačila zavarovanj v kmetijstvu. Po drugi strani so lahko pametne pogodbe izpostavljene hekerskim napadom, kot je ponovni vstop, ki v večini primerov privede do izgube kapitala. Ker je tehnologija še v zgodnjih fazah razvoja, bi lahko povzročila visoke cene plina, če bi se pogodbe morale ukvarjati z ogromnimi količinami podatkov, kar pomeni, da imajo takšne tehnologije težave s skalabilnostjo. Glede na to, da je ta industrija še v razvojni fazi, primanjkuje kompetentnega IT kadra, ki bi lahko razvil varne sisteme, premalo pa je tudi raziskovalnih in razvojnih projektov za tovrstno tehnološko infrastrukturo. Hrvaški kmetje, ki so bili intervjuvani za potrebe magistrskega dela, niso bili seznanjeni s tehnologijami in imajo različna mnenja glede njihove uporabe. V primeru, da prinaša več nepredvidenih stroškov, niso naklonjeni k uporabi le-te, pripravljeni pa bi bili avtomatizirati svoje vsakodnevne procese in potrošnikom omogočiti preglednejše informacije. Kljub temu so tehnologija veriženja blokov in pametne pogodbe popoln nabor tehnologij, ki lahko izboljšajo poslovne procese v verigah preskrbe s hrano. Boljša izmenjava informacij in preglednost bi povečala zaupanje med lokalnimi kmeti in potrošniki, kar bi usmerilo povpraševanje in tako bolj podprlo lokalna podjetja.

APPENDIX 2: INTERVIEW QUESTIONS

- For how long have you been in the agricultural business, in which agricultural sector are you focused in and how many ha of land do you cultivate?

- Are you familiar with the recent technological developments and do you use computers on the regular basis?

- Are you familiar with IoT sensors and smart farms?

- Have you heard about the blockchain, and what is your first association when you hear the word blockchain?

- Are you familiar with the technology behind blockchain?

- Are you familiar with technology behind smart contracts?

- With what problems are you faced on day-to-day basis when operating an agricultural business?

- What are most common obstacles that you are faced with in the existing food supply chains?

- Since smart contracts can bring the automatization in solving a lot of paperwork and financial transactions, how do you think it can impact the traditional agricultural business processes?

- To improve the effectiveness and provide more detailed and clear information to the customers, would you be willing to invest towards a smart farm architecture?

- Do you have any experience with the ecological production supported by the EU?

- How has the removal of pesticides impacted the amount of the production of crops?

- Would you be willing to shift to more technological-oriented solutions if that would help to solve the problems of climate change?

- Smart contracts offer automatic contract execution based on the conditions written in the contract. One of the proposed examples of such use is the insurance. What do you think of smart contract's usability in the agricultural insurance?

- What do you think of technologies such as IoT devices and smart contracts to share the information about the product's life cycle on the farm?

- Do you think that providing consumers with more clear information about the products, such as, the microbiological state of the milk, when was the milk collected, temperature during the transport etc., will have an impact on consumers perception of the product?

- What is your experience with third-party brokers through which you would sell your goods such as wheat or corn?

-Have you had any problems with third-party stakeholders, such as late payments on service provided?

- Could you give me an example of where you think implementation of proposed technologies could help you?

- Would you be willing to go on educations to learn about blockchain, smart contracts and IoT?