Utilizing Blockchain and IoT in Food Network: Systematic Literature Review

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University of Turku
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Tommi Tocklin

UNIVERSITY OF TURKU
Department of Computing

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Food is required by everyone daily and because of this various supply chains have to operate smoothly to deliver quality goods to nearby stores. These operations contain several different parties and each one of them performs critical tasks. These supply networks can become very complex and their management can be a hassle. This complexity creates several challenges that could be solved with a single common platform that everyone involved uses. This approach, however, would be flawed with a centralized solution, so we need to turn into decentralized solutions like distributed ledgers.

Currently consumers do not know much about the food products that they buy and eat. The goal in this thesis is to research how using blockchain technology could improve food supply chains since they face several issues currently and anything that can solve or even alleviate those would over time have a big positive impact. Currently the exact origins of products are mostly unknown due to lack of transparency and lots of food is wasted and thrown away due to various reasons which is not sustainable.

Technology can provide new solutions for these issues which also involves IoT devices. Combining blockchain and IoT together can provide much safer and more transparent food supply chains for the masses. There are also several other related issues with food that could be improved, including supply chain optimization, collaboration and better data sharing. The used research method in this thesis is Kitchenham's systematic literature review.

The results in this thesis cover extensively how distributed systems can benefit the parties involved in the food value chain and how these could be utilized for several things. Some potential concerns with the performance of these distributed systems and their security are also discussed.

Keywords: Blockchain, DLT, Distributed Ledger Technology, IoT, Internet of Things, food, supply chain, distributed systems

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1 Introduction

Blockchain has gained a lot of attention thanks to various cryptocurrencies popping up. Despite their questionable implementations and purposes, the technology has been proven to work really well on a large scale. Blockchain could be very beneficial platform for other practical applications since it is basically a distributed database where the data is stored permanently[1].

Data is collected almost everywhere currently, and it has in a way become a new digital oil for companies. Keeping it secure is also increasingly important as various digital attacks and leaks have become more common. In case of the food networks, the collected data can be used to optimize deliveries better and farm crops more efficiently. This all can also help with the emissions by reducing the unnecessary transportations. CO2 sinks like farmland and forests can also be used as a counter for the emissions. CO2 flux can be measured from these different fields for example.

Blockchain can be useful in several practical use cases, but it especially shines in the supply chain since every step of the production should be logged. Supply chains are getting more complex and also more global, so these various steps in products' life cycle should be logged somewhere[2]. The best approach would allow monitoring of the entire chain in real time which can be critical for ensuring the flow and safety of products. Also forecasting can be used to model some of the incoming trends if the data for that is available[2].

There are lots of things happening around the world and these global trends can

be referred to as mega-trends. These include several different pressing issues like the climate change and people moving to cities. These problems require good solutions and blockchain could be a part of those since it can ensure that the stored data is not tampered, and thus trusted platforms are formed. The general trend currently with food seems to be that people want to know more about where the products come from and other details about them. A trusted system for this purpose can be done with blockchain technology.

This thesis takes a through look into decentralized blockchain systems and real-world applications for this technology. Another key topic is how this technology can potentially improve the current situation with food supply chain tracking and safety among other related topics. The key features of blockchain are also covered since these apply to distributed ledgers since this technology is based on blockchain. Detailed scalability and performance analysis of various blockchain platforms is a very large topic and requires further research and it will not be covered here.

1.1 Research question

This thesis was performed as a systematic literature review that analyses articles about the chosen topic and aims to answer the question: *How blockchain based distributed platforms and IoT can improve the current food supply systems?* Practical use cases for this technology are not very common yet but there is great promise.

1.2 Methods

The applied scientific study method is Kitchenham's systematic literature review Kitchenham, Pearl Brereton, Budgen, *et al.* [3]. Blockchain is currently a very popular topic so very vague searches provide way too many results. Because of this plenty of time was spent formulating good strict search phrases for the various

sources available. Also, the fact that there are several alternative words for these subjects further bloated the chosen search phrase was formulated to include publications that contain IoT and blockchain technology along with the food logistics sector.

(IoT OR "Internet of things") AND (blockchain OR "smart contract") AND (supply OR product OR logistic OR manufact*) AND (food OR grocer* OR beverage OR drink OR farm)*

Essentially the searched topics were IoT, blockchain technology and food logistics related. The search was done in between 7.12.2019 and 19.12.2019 with the criteria that the selected results were scientific publications, written in English and the abstract description matched selected topics. There were lots of duplicates in the different databases, so those were left out. Additionally, any limited access content was filtered out if the database had such publications. The selection process is illustrated in the following Figure 1.1.

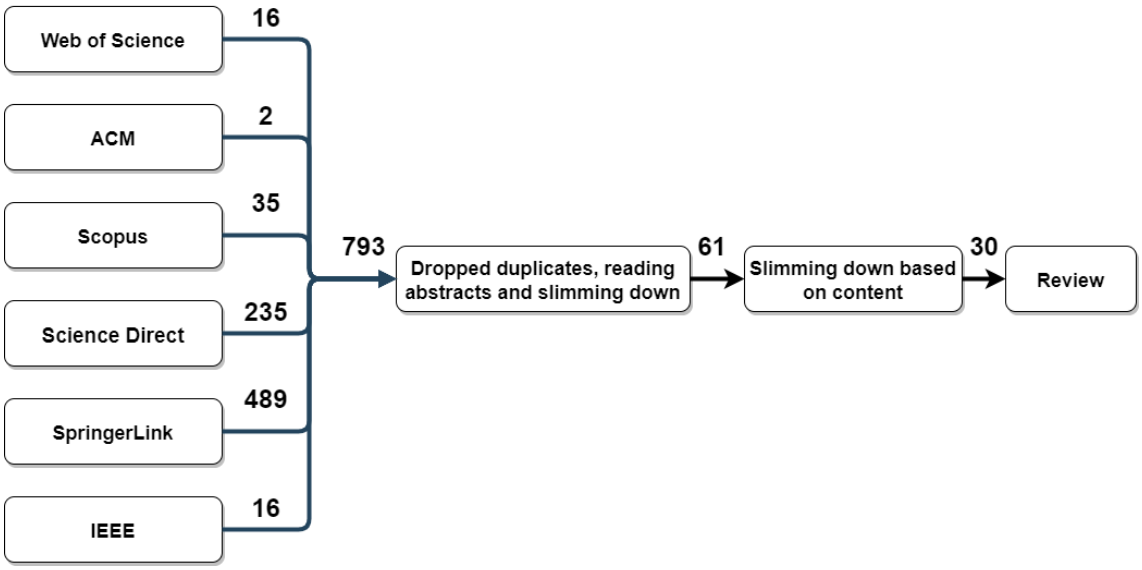

Figure 1.1: Selection process

There are many different platforms available for implementing your own blockchain

applications, so I favoured publications that mostly focus on Hyperledger Fabric and some Ethereum since they are both currently very popular. I focused on very recent publications when the search was done since blockchain is a very active research area and the field is moving rapidly forwards. Also, bibliography network analysis publications were not included since they do not fit my interests in this review.

There were few publications that were very short and their sources were pretty low quality material so those were not included either and some several years old publications were left out since this field moving so rapidly at the moment. Several publications also had architecture suggestions for various implementations. I have some key points of them covered here and my own suggestion for utilizing a distributed ledger with existing systems in Chapter 5.

1.3 Motivation and objectives

There are many ways to store data, commonly databases, but these implementations are a bit lacking in certain use cases like when the data originates from several different parties and it is meant to be trustworthy. Blockchain is currently one of the technologies that can be used to ensure that the stored data has not been tampered by someone. Collaborative networks, including food supply chains, could gain several benefits from a system like this, which promotes sharing more data with the other parties and the end customer. Over time the collected data can even help with important business decisions thanks to various data analysis methods.

Blockchain in food production chain has lots of benefits including the added transparency of each step the product has gone through. The origin and timestamps of everything can be essential for avoiding food-borne illnesses and other issues within the supply chains. Optimizing local product transporting to reduce emissions among other benefits could be also achieved with a system that focuses on logistics. These additional services also have the potential for increasing the value of the

product. Customers getting more information about the products that they buy is a very essential next step for consumables.

Combining Internet of Things (IoT) and blockchain can potentially add trust to various measurements from various remote devices too since automatic measurements are more trustworthy than manual measurements done by humans. There is a big increase happening currently with these connected devices since they tend to be very affordable and efficient at specific tasks. IoT has some potential flaws currently but even those can be solved, which could even utilize the blockchain technology.

1.4 Structure

In Chapter 2, the blockchain basics are covered which also includes its types and some practical uses. Distributed ledger technology is another a key topic which introduces some new business-related ideas into blockchain applications. Also, various benefits and shortcomings of this technology is also covered.

Chapter 3 is the research review which covers the selected publications. This is all about building a trusted decentralized platform for food products and logistics. Along with blockchain technology, IoT is also needed for achieving trust and efficiency. This chapter also contains relevant background information about the food sector, current systems and their flaws.

Chapter 4 focuses on utilizing the blockchain technology in a food network. This includes various possible hurdles in adopting brand new technology and combining it with IoT and the effects of this integration. Utilizing blockchain in a food network is not an easy undertaking but several different companies have created specific pilot projects and some of those are covered here.

In Chapter 5 I have a suggestion for a trusted food platform. This utilizes a distributed ledger and IoT devices alongside current systems since the complete sudden transition to ledgers is not very feasible. This way the possibly very rough

move towards the distributed systems can be made a bit more smoothly and perhaps expanded upon later.

2 Blockchain

Essentially blockchain is a list of records that are linked together and each of these records can store a list of transactions[4]. These linked records form a chain that can not be altered without breaking the chain which makes it trustworthy. The first practical implementations involve cryptocurrencies. These decentralized public networks have basically proven that blockchain can work in large scale without major problems. This has led to blockchain being a very active research topic since adapting this technology to other business centered applications can introduce new possibilities with distributed trusted storage and decentralized platforms. The key areas for this technology are typically things that require trust and transparency such as food products and their origin.

Blockchain is designed to be distributed, which means it is not centralized like normal databases like MySQL, PostgreSQL and MongoDB. Certain blockchain platforms are pretty much immutable databases like BigchainDB since it supports database functions like structured queries and the performance is great[5]. On the other hand, certain blockchain systems like Bitcoin do not match the database description since they do not share these properties[5]. There are some other upcoming custom blockchain based platforms like Azure SQL Database ledger in the works also[1]. All these blockchain based platforms utilize the immutability to avoid data tampering and the chain is typically managed using a consensus mechanism, where

[1] `https://techcommunity.microsoft.com/t5/azure-sql/announcing-azure-sql-database-ledger/ba-p/2200401`

the chain members verify additions to the chain.

Blockchain has potential for more things than just implementing new cryptocurrencies. There are several researches ongoing for figuring these optimal use cases. Currently these are focusing on creating trust in several fields that are not currently transparent enough. These possible areas of use include food products, cargo transportation, medicine and much more. The blockchain system can be shared with all members of the production chain and thus improves efficiency. Currently all members might be using their own systems for logging things. Also, the performance of a production chain can be improved using Internet of Things devices to avoid manual work. The big drawback with blockchain is that it is not very mature and well-known platform for these applications yet.

The decentralization is important for certain uses. Currently various production chains are not very transparent and there has been multiple scandals and frauds for several different food products over the years. Good quality and safe food products are obviously very important for people and their well being. With better tracking and transparency these issues and frauds could possibly have been prevented or noticed earlier since somebody could have checked the origin and the other statistics of the product. Though it is worth to mention that the product tracking and authenticity systems do not have to use blockchain to be efficient but blockchain is vastly better for certain applications.

Blockchain is mainly useful when the data needs to be shared to somebody and that data needs to remain trustworthy. You do not need blockchain for all your data storage and I do not see more traditional databases going anywhere. Databases are still very good options with their own benefits and disadvantages just like blockchain. Having both, database and blockchain, in use at the same time could be another good option. There is currently a lot of unnecessary hype around blockchain and how it will change everything in various fields but some of

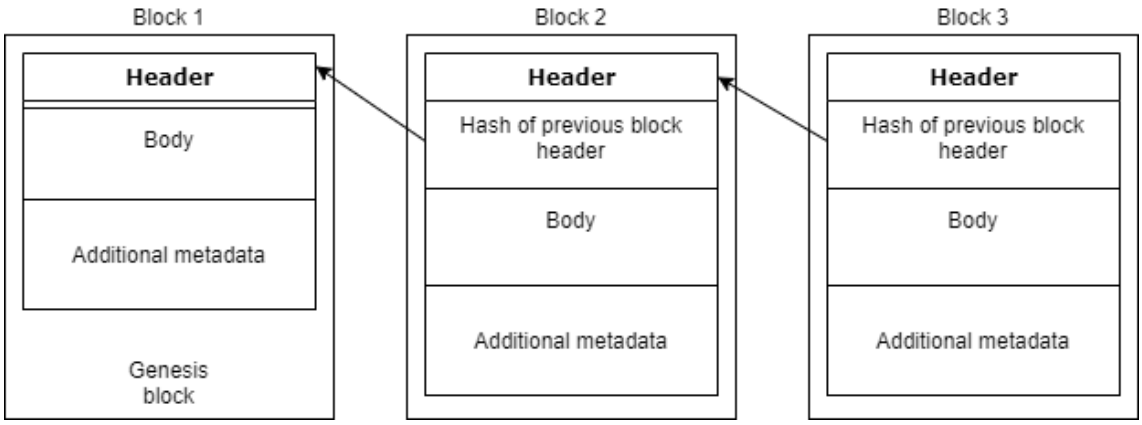

Figure 2.1: Simplified blockchain structure

the proposed use cases are not that impressive or realistic. The big question is, does your blockchain based implementation actually bring something new that could not be achieved with databases?

The first block in the chain is more special compared to the other blocks since it can not point to anywhere as seen on the structure Figure 2.1. This block is usually referred to as the genesis block. Each block in the chain has their own calculated hash which are used to form the chain. If a block is altered, the hash of it changes and this breaks the chain. These blocks can be used to store pretty much anything in their body and some optional metadata may be automatically added depending on the system.

Public blockchains can be inspected freely with different explorer tools available on the Internet since there are no permissions to limit that. Public chains are currently the most common permission implementation thanks to the huge popularity of the various cryptocurrencies. These platforms are permissionless, so they are available for anyone to join and because of that they scale up quickly and require more strict consensus methods.

2.1 Consensus methods

Without a consensus method (also known as consensus protocol) decentralized platforms would not be possible. This applies to all blockchain based applications since there would not be any safeguards for ensuring the integrity of the data stored in the chain. Public permissionless blockchain implementations typically must rely on a very resource intensive consensus protocol, like Proof of Work (PoW)[4], in order to keep the chain intact. The consensus protocol is essentially used to validate transactions using the other nodes (or peers) in the network[4].

With PoW the attackers need to control over half of the network's computing power in order to be able to tamper with the system. PoW is very inefficient in terms of power usage but it can keep the public systems in check, as seen with cryptocurrencies like Bitcoin and Ethereum. PoW has received lots of criticism and there are several alternatives already out there for this protocol. Ethereum is planning to move from PoW`https://ethereum.org/en/developers/docs/consensus-mechanisms/` to Proof of Stake (PoS) in the future, which is by far more power efficient since the transactions consume less energy thanks to relying on validators. Proof of Understanding (PoU) is a more IoT oriented consensus protocol which also consumes little energy since the peers agree on the message meaning in this method[6].

PoS consensus protocol can overcome the need for the huge amounts of calculations and power usage by using the peers as validators instead of miners. With this method, the validators stake some of their cryptocurrency for the validation process. With this process, doing it incorrectly may lead to the validator losing the staked currency. Also staking more earns you higher chance of becoming the next validator. While this consensus method has additional risks compared to PoW, the potential improvements can vastly out-weight those. PoS may not be suitable for new blockchain networks but after they have been running for a while, cryptocur-

rencies could transition to it later like Ethereum is planning to.

With the PoS, overtaking the system would require the user to own over half of the staked cryptocurrency. This might be unfeasible, since you might need billions, for this attack depending on the value of the cryptocurrency. Though the values of cryptocurrencies are very unstable so there are some concerns. This method also incentivizes people from setting up several validator nodes and thus increases the decentralization unlike the mining pools with PoW which causes centralization.

There are also lots of other options for the consensus mechanism which could replace the power hungry PoW for public blockchain platforms. Leased Proof of Stake (LPoS) allows users to lease funds to other nodes in the network, so that they are more likely to be selected for the next block creation, increasing the number of electable participants, and therefore reducing the probability of the network being controlled by a single group of nodes[6]. Rewards are proportionally shared with this method[6].

Proof of Burn (PoB) proposes getting rid of some of the coins by sending them to a verifiable unspendable address, in order to publish a new block[6]. This mechanism is hard to exploit and easy to verify. It also requires no major calculations, so no additional energy is used for the consensus[6]. Also PoB has some economic implications that could contribute to a more stable ecosystem[6] though PoB is not still very mature so you can not really tell how well it would actually work. There are so much more of these different proposals for consensus methods with different goals and shortcomings. And on top of those there are even extended versions and combinations with certain desired features.

Private permissioned blockchain systems can only be joined with a permission and these networks may also have some special features for their use cases[6]. Typically these networks have less participants than the public ones so the reliability of peers should be higher. Because of these things, these networks normally have a

different consensus method in use, though all of them are still usable but perhaps unnecessary. There are several options but they mostly center around the fact that some of the peers are given more important roles in the upkeep of the network[6]. It is worth to mention that there are some hybrid blockchain implementations that blend public and private implementations together.

There can be several types of nodes in a blockchain network, and these also affect the optimal consensus methods. Certain types of nodes are more limited, while full nodes store the entire blockchain which is used for full validation of transactions and blocks[6]. In 2018 it took more than 150 GB to store the entire Bitcoin blockchain and 46 GB for Ethereum[6]. This makes similar deployments on very hard in IoT devices since most such devices will not have the capacity for it and other requirements are not met either. Luckily there are some options to cope with the limited nature of IoT devices.

Lightweight nodes can be used for validation without storing the whole blockchain so they are more suitable even for IoT devices[6] however this process should always be backed up by full nodes. The consensus protocol could also be more relaxed to facilitate the inclusion of IoT devices, however this could compromise the security of the blockchain implementation[6]. All of blockchain platforms do not support lightweight nodes though[6]. IoT connectivity can also be very spotty, so required participation and full consensus from the network can cause problems[7].

There are lots of different consensus protocols available, but most can still be considered untested and PoW is clearly dominating the scene at the moment. These various implementations have different security properties[4] and on top of that some of these consensus protocols are more resource intensive than others. The most optimal choice highly depends on the fact whether the network is public or not.

2.2 Use cases

Blockchain itself is essentially a distributed immutable ledger that keeps expanding as more records are added into it[7]. The formed sequence of blocks is not alterable after the addition to the ledger which makes it great for certain applications[7]. Each block addition is stamped with metadata, like timestamp and block size, and then linked to the previous block with cryptographic hashes. These transaction hashes are arranged as a Merkel tree to produce a single hash (Merkel root) for the block[7].

With full nodes, each member of the network maintains a local copy of the entire chain and participates in the upkeep of the system. These nodes take part in several tasks like adding new blocks and the consensus protocol. This distributed upkeep process makes the stored data in the blockchain immutable and tamper proof[7]. Usually you can not call all blockchain implementations distributed ledgers, since not all of them support specific features like smart contracts and permissions.

Arguably the most promising use cases for blockchain includes the identity management, traceability systems and internet of things integration. All three of these are in its current form very troublesome and flawed in different ways. These areas were chosen as the main topics for this thesis since all of these three are very important for the whole food logistics and tracking system and they will be covered in the following chapters. Blockchain has plenty of potential in the food logistics and production chain area currently compared to the some of the other previously mentioned cases in my opinion which might take longer to become more mainstream.

Blockchain provides a promising shared decentralized platform for many things and the current hype for it is in my opinion at least partially justified. Some of the current ideas and use cases do not make a lot of sense so far but as this technology matures more, there will be even more options available in platforms, consensus, hardware and use cases. All tasks or applications do not require the blockchain for anything though. Over time there also has surfaced different ideas and platforms to

utilize blockchain like distributed ledger technology for real-world applications and systems.

2.3 Distributed ledger technology

Distributed ledger technology (DLT) is a more advanced implementation based on the blockchain technology that basically enables more complex implementations of various real-world applications. Distributed ledgers also tend to be more business oriented and private, so you can join this network only if you get an invite. However, distributed ledgers are maintained by the participating network of mutually untrusted nodes[4] just like the other blockchain networks in general.

The ability to use smart contracts and assigning various permissions for performing certain tasks and accessing the stored data makes DLT special. Nodes in public blockchain implementations can add and read transactions freely but with DLT the nodes may have restriction for these tasks. On top of those basic activities the nodes can participate in the consensus protocol as covered earlier in chapter 2.1.

Ledgers are not a new thing but decentralizing them is a fresh concept with great promise. Distributed ledgers can be used for different fields such as food production chain and various production chains. Different products can be tracked from their origin using the immutable stored information very quickly compared to current methods. This approach allows consumers to check the origin, transportation, refinement and various other details of the products that they use or consume. Along with that blockchain also ensures that the displayed information is accurate since it can not be tampered afterwards. With normal databases the same thing could be implemented but due to the centralized nature of databases, the data can be tampered by somebody which makes it less trustworthy.

DLT provides a promising base for other areas such as smart homes, smart grids, healthcare and smart cities[4]. There is a big difference with these compared

to the public blockchains. These implementations may need more performance that the public blockchain can not provide like lower latency and higher throughput[4]. Anonymity might still be desirable or the peers must be identifiable in some cases[4]. Either way this totally depends on the use-case and application, but both should be attainable even though the anonymity is one of the selling points of blockchain. Some regulations might require the nodes to be identifiable with these real-world applications.

There are some alterations of distributed ledgers and other blockchain platforms available currently, these mostly center around different views about the data sharing and chain permissions. Permissioned private blockchains are limited to approved members only and the permissionless ones are open for anyone to join. Various applications mostly rely on the permissioned blockchain which makes a lot of sense since these implementations have a set of known, identified participants[4].

Since these private networks can not be joined by anyone freely, there are several benefits like better performance and smaller storage size requirements. Also, by relying on the identities of the peers in the network, a permissioned blockchain can rely on traditional Byzantine-fault tolerant (BFT) consensus protocol. Typically, distributed ledgers do not require methods like PoW since everyone can not join them freely. There are many different implementations of these permissions already in use and some hybrid implementations where the network has some features from public ones and some from private.

DLT has many desirable features for sharing information securely and ensuring the content integrity. The permissions that were just covered are a big part of DLT and smart contracts are the next big feature. These small script-based programs can be used to automate repetitious things like ordering automatically certain resources or items when your storage is past certain threshold. These contracts are reviewed and approved by both of the peers so there will not be any surprises. This has a lot

of potential for reducing the amount of paperwork for example with various orders.

2.4 Key features and benefits

Blockchain's one of the most desired features obviously centers around the decentralization. This approach can increase transparency and trust among the other peers in the chain and the end customer with tracked products. This can be used for increasing the transparency of a supply chain as an example. Thanks to decentralization the whole system is not just reliant on one of the parties in the whole business network. Rather than that, the network is managed by the peers in the network more equally.

Depending on the required task, distributed ledger and its features can be very useful. If the communication and data sharing are well-known key requirements for the system, distributed ledgers are one of the best options currently available for that. The decentralization can pretty much guarantee that no stored data will be lost since other nodes have the whole blockchain stored in cause one of the nodes fails. This allows pretty easy hardware swaps unlike in systems that rely on a single machine in a single data center which could be lost.

Every transaction in a blockchain is permanent since there is no way to modify the existing transactions. This feature is very important in distributed storage so other peers in the network can not forge records which means everything is logged to the chain permanently. This increases the trust compared to normal centralized databases for example. Upon a transaction, other trusted peers in the network verify the transaction which makes the system more secure. Blockchain can be used to respect the privacy of users by keeping the identity a secret[8]. This anonymity can be valuable in certain use cases. This can be achieved with other more common technologies but they rely on the users trusting the host to ensure privacy.

Most of the things, like food product information, are already logged in separate

private spreadsheets or systems. This is a big issue in terms of efficiency and logistics[8]. Shifting towards a more optimized supply chain where there are more direct ways to check and contact the origin of the goods rather than trying to contact each stakeholder one by one or forwarding the messages along the chain. With current systems and their implementations, each stakeholder in a supply chain has their own data bubble and this simply does not allow the information to flow between stakeholders.

2.5 Shortcomings and challenges

Blockchain and distributed ledgers are still being actively researched and development of various platforms is progressing along with it. Various applications that utilize these platforms have been steadily popping up for several domains including the food supply chains. However, one big issue with this technology currently is that it is not very well known in general which can be seen on the very slow adoption everywhere. Even though distributed ledgers might be one of the most practical technologies to use in different fields. Another big problem is the process of figuring out the best use cases for it. Food and agriculture sector has been somewhat active area recently since several systems and implementations were proposed and tested in various publications.

Public blockchain system can be joined by anyone and after that the new node can do all of the basic blockchain tasks, like reading, mining, audits and reviews, since there are typically no permissions for these actions[9]. Some of these restrictionless systems may have potential legal issues in the future when blockchain technology is more known[6]. There is a chance that several governments and their regulations may affect several blockchain based applications in the future. However this is mainly a major concern for the public networks, which mainly covers all of the cryptocurrencies currently.

Various transactions in large public blockchains consume a lot of electricity due to the PoW consensus, as mentioned in chapter 2.1. And because of that they cause lots of unnecessary CO2 emissions since there simply is not enough clean energy available which definitely does not help the current climate change trends. Using renewable energy exclusively for this can solve the issue but the serious miners probably can not get enough electricity for their massive calculation loads this way. The transaction energy cost in networks that use PoW can not be ignored since it is very inefficient.

There are several other typical attacks on blockchain systems like double spending, consensus protocol exploits, eclipse, and distributed denial-of-service[10]. On top of those, blockchain can also have issues with programming frauds, smart contract exploits and private key leaks[10]. Also, the forming of large mining pools can be seen as a major threat since it makes the blockchain more vulnerable to majority takeover attacks[6]. This is a major flaw since it also creates centralization which is the opposite of what decentralized currencies and platforms were meant for.

One major potential issue with distributed ledger technology is the potential lower performance than traditional storage[4]. The consensus mechanism can be very resource intensive depending on the chosen method and because of this the system very likely can not compete with more traditional centralized storage in speed. Alternatively, you could pick a less resource intensive consensus mechanism but those might have other drawbacks like less trust and easier takeover attacks.

All of members typically store a full version of the blockchain which can lead to storage space issues but on the other hand storage has become more inexpensive over time. This requirement however pretty much instantly rules out IoT devices acting as full nodes in the network. There is also the option for limited nodes but those are not always supported depending on the chosen distributed ledger platform.

The performance of the blockchain can degrade over time as more data is stored

in it[11] which is a major concern in the long term for certain systems that require very fast updates. Used hardware and connectivity also affects this. In certain areas physical connections may not be available and wireless can be slow or spotty time to time. Also, the whole system can have weak spots in terms of security of the system like how the measurements are processed and stored in the blockchain, which will be covered in the following chapters.

2.6 Platforms and implementations

There are several different platforms already out there in use with blockchain and DLT based systems. These platforms have various common features, but they still have key differences. IBM's Hyperledger Fabric is based on Hyperledger, as the name suggests, and it adds more features on top of that platform. Both are used to implement distributed ledgers with permissions.

Hyperledger Fabric is currently one of the most popular platforms[4] and therefore I am taking a very brief look at its features. This platform does not need a reward coin for the consensus mechanism unlike cryptocurrencies[4] which is typical for distributed ledgers since they mainly focus on business tasks. Hyperledger is also highly modular and it supports smart contracts like the other distributed ledger platforms[4].

While a custom blockchain platform can be implemented from scratch too, implementing all of the features that these other platforms already offer is going to take quite a while and this just makes it unfeasible to create and use custom platforms for actual projects. Similarly, you probably do not want to create your own programming language or a custom library for a project when there are already great existing options available. It makes more sense to select a fitting base that already exists to save some development time and money.

Since some of these platforms are also open source, you could even add new

features or modify them to fit your needs if necessary. Even IBM decided to extend the Hyperledger platform instead of creating their own. Also, the communities surrounding these platforms can often help when you run into various issues with them. There are lots of other Hyperledger based platforms[2] available like Sawtooth, Besu, Indy, Iroha and Burrow. Each of these specializes in something specific and offers suitable features for that domain.

Hyperledger Fabric is more suited for enterprise applications since its performance is optimized for appropriate tasks. With this platform the users can be grouped into several organizations which is an essential feature[4]. For each organization there might be several types of users depending on their roles on the blockchain[4]. Each user is a node in the blockchain network and takes part in the upkeep of the network.

There are already several platforms available for building distributed ledgers and other blockchain based systems and over time even more branches and maybe even completely new ones. One great trend with these is the fact that most of the popular ones are open source which allows new variations of these platforms to emerge. There is definitely a lot of research and collaboration required to improve even the currently popular platforms with new features like better consensus protocols.

[2] `https://www.hyperledger.org/`

3 The discovered literature

In this chapter I follow the method of a systematic literature review, as described in the Chapter 1.2. Focusing especially on the present state of food supply chains and new technology integration possibilities. There are currently very few blockchain applications implemented and they are mostly for limited demonstration purposes. This is at least partially caused by the general lack of knowledge about blockchain[8] even though it has several useful features for different tasks.

While cryptocurrencies are more known, they are not as useful compared to these more creative implementations. Despite that I expect distributed ledger technology to gain a lot of popularity since there is not really any alternative distributed trusted storage methods available. Perhaps a very popular and large implementation is required for DLT to become a mainstream technology in data storage. Currently it is more on the buzzword side rather than a popular tool.

3.1 Findings

People need food to live so food production chains are very important for the general well-being of people. These production chains are not typically very efficient and they face multiple issues often like wasting good food due to spoiling and lack of accurate origin information[7]. Old inefficient ways to store data also contributes to the inefficiency. Luckily there are many ways to improve the chain performance and efficiency for more sustainable farming and food production [12].

Potential benefits of a upgraded system could include accurate origin, more agile supply chain[7] and detailed tracking of each step in the production. This optimization has also potential to make the food that people consume more affordable, safe and nutritious. Alternatively, it could create a more premium product that the other competitors may not have available, similarly to organic foods.

Nowadays various types of supply chains can form very complex networks which need technology to function efficiently. This approach typically includes IoT devices or even Wireless Sensor Networks[13], which are formed from several cheap sensors. This allows constant monitoring and tracking using the available sensors. It is not necessary anymore to do these monitoring tasks manually which can reduce labor and other costs. On top of that the collected data should be more reliable than the manually collected data[13].

These large production chains can face many challenges which need to be solved for optimal performance[8]. Producing as much as possible locally and delivering products to nearby markets can reduce the emissions and transportation costs and even the longer deliveries can be optimized better using technology and planning[7]. Each party involved in the supply chain probably has their own issues currently related to used systems and technology. Especially farmers may still use more traditional methods for farming[13]. Relatively simple physical or digital spreadsheets are still a common way to store information.

On top of the supply chain issues and optimization, food safety has been an important topic for several decades now. This is due to several food scandals around the world which ends up affecting the consumer confidence negatively[14]. Each year, roughly 48 million Americans get sick, 128000 are hospitalized and 3000 die from a disease caused by the food that they consume according to Centers of Disease Control[7]. These food quality issues can make people more conscious and maybe even fearful of what they eat since various food products simply do not include much

information.

There is not any trustworthy way for consumers to verify the origin of the product even if the packaging says that it was produced in a certain country. This issue is also possibly made worse by the various chemicals used in the farming and refining processes. Farmers might commonly use certain chemical pesticides and fertilizers which could be very toxic and cause health hazards from the leftover residues[15]. Certain areas might get polluted by illegal waste dumps or by other means and this also causes potential health hazards. Even bad raw materials can also be a major risk since products made from sick animals can cause issues for humans. On top of that excessive chemical usage in food processing also has potential for causing long term health issues.[15]

Most of these potential issues could be reduced or eliminated with increased monitoring which would be involved in this trusted food traceability project anyway. It can also help with the sales of exported products since certain countries might have less pollution in the air for example and the sales of the exported food products can capitalize on that. The increased data collection could also finally transition farming into smart farming where human effort is reduced while maximizing the available resource usage[15].

This increased tracking has also potential for shifting towards e-commerce. Even a small farm could have their own trusted online store since every product would have proper tracking information available with a selectable pickup point potentially reducing a lot of useless transportation and carbon emissions. On top of all these, proper trusted tracking has also potential for reducing wasted food by offering accurate information. Without this the whole batch is likely to be thrown away even if only few items in it are bad.

Quality checks for crops, animals and soil can very time consuming and common tasks for farmers[13]. Most of them can be done with appropriate sensors so utilizing

various IoT devices for these tasks makes sense. This process would be shifting the farming slowly towards more automated and optimized farming, saving the farmers' time from repetitious tasks for other tasks. All the collected data or selected relevant bits of it could be stored in the blockchain and linked to the item so it is included with the finished product. Origin tracking is very important, and it is kind of in use in several places already. The current problem with it is the data asymmetry between different parties in the supply chain. Basically, everyone has their own private systems and data which makes tracing the product very time consuming and inefficient. These also increase the risks of various digital attacks since this data is very critical for safety[13].

Currently most companies already have these tracking systems implemented to a certain extent[16] but they are not very extensive yet so there is room for improvement. Most of the useful fine details are not currently tracked and the different systems do not work together. Another major issue currently is the fact that everyone has their own systems that create a tangled web[16]. This can cause several issues with tracing the origin and history of the product, especially globally thanks to the messy web infrastructure.

3.1.1 Food safety and solutions

In 2006 North America had a potentially deadly E. coli bacteria outbreak related to fresh spinach that caused lots of general illness, some deaths and kidney failures[16]. This issue caused a temporary ban for consuming fresh spinach and related products in the United States. This ban obviously caused issues for everyone participating in the spinach supply chain since they were not able to trace where the issue originated from. It took 2 months for the local administration to trace the source of this issue to a single farm. With a better tracking system, the ban in the whole country could have been avoided completely[16].

A bit more recently in 2017, there was a salmonella outbreak caused by Mexican papayas. In this case it took also two months to track down the origin of this issue[7]. This incident involved also a large and complex supply chain which led to lots of unnecessary recalls, loss of trust from customers, illnesses and deaths[7]. Similar issues keep popping up now and then to varying extent and severity around the globe and there seems to be no end in sight with these problems currently. According to the World Health Organization (WHO), it is estimated that every year around 600 million people in the world suffer illness from eating contaminated food and 420,000 people of those die from this[6].

The main point with bringing up these issues is that most of them could be completely avoided with better tracking and transparency. On top of that the potential market changes after these incidents could also be avoided with the increased trust among consumers and pinpointing the source of the problem. It is very common for people to be more concerned about the products that they choose after these food scandals happen. Because of this many companies have already started to search for potential solutions and blockchain is typically related to them since it is a suitable trusted information storage method.

Food safety problems are luckily quite rare nowadays in certain countries like Finland, but meanwhile some countries have these issues more often. Labeling and monitoring products has clearly progressed forwards to avoid most of the potential issues, and recalls are more fluid, but there is still room for improvement. More strict laws and active authorities for checking food products matters.

On the other hand, manual monitoring is horribly inefficient and stalling deliveries for quality checks will reduce the shelf life of products. Some of these products may also lose their fresh look and marketing appeal over time. Bananas are pretty good example of this since they are well known to sell less efficiently when they start to darken a bit. There is a constantly growing demand for quality and plentiful food

products around the world. Digitalization and upcoming related food technologies can help in meeting these rising demands and improve several other things along with it[13].

There are currently several different labeling systems and standards in use for various products including foods. They may include attached labels like GS1, GTIN, lot and batch numbers. Some retail chains might even mandate these already[7] which demonstrates clearly how useful they are. GS1 makes quick sale stops and recalls possible in certain countries where a system like this has been implemented for this particular purpose. However, there are no common standards for an in-depth food tracking systems since everyone has their own internal systems[17] and the coverage could be much better[7].

Centralized systems are fundamentally flawed for storing data from several parties in a trustworthy way. The data can be tampered by pretty much anyone that can access the system with proper permissions like administrators or developers[7], another party could try to gain competitive advantage by tampering with another party's data. Incorrect configuration and other similar mistakes can compromise the whole system[18] and there is a risk of even bribery. Single point failures are a major concern with online services. Inevitable hardware failures are also a problem over time and various remote attacks with connected devices[14] which seem to be getting more and more popular.

Due to these possible issues, using traditional storage is not very suitable for critical things like food. It is very hard to make the stored data in these systems trustworthy for other parties and some individual party probably owns the whole server or the virtual machine. This single point of failure is a major issue in several ways. With a shared system, like a distributed ledger, all the parties involved are responsible in keeping it running in good condition so there is nobody with excessive rights. Though certain parties might have more responsibilities, like approving new

additions, in the upkeep of the system if desired.

There are several different blockchain based platforms for decentralized information storage already available. These distributed ledgers are typically very specialized or more business oriented than typical blockchain implementations and they support smart contracts as mentioned in chapter 2.3. BigchainDB is a very unique example of these platforms since it attempts to grab the desired features from databases and the blockchain to create a high performance decentralized immutable database[14].

There have been multiple major food industry revolutions over time. One of the recent ones is the use of connected devices thanks to extensive networking possibilities. Combining physical and digital systems has the potential to be the next big thing. A system like this can be implemented with the blockchain for example for trusted data storage and identities. This has potential for encouraging local processing and shortened transportations. So, in the other words the food production can potentially become even more local, profitable and trustworthy[19] or more global as mentioned before, this highly depends on the business goals.

Certain regions are more suitable for growing specific crops and fruits so these areas or even countries can potentially capitalize on that with their exported food. The amount of pollution varies a lot based on the location. There are some concerns with the climate change on specific areas since it causes issues like ruining farming locations in the worst case. Smart greenhouses might be a feasible solution for these potential issues. The Barents region has lots of food production despite relatively harsh environment and varied seasons[19]. Smarter farming has plenty of promise to increase the yields despite climate change causing issues.

3.1.2 Blockchain of trust

The potential trust issues with product origin can be solved using blockchain for storing the historical data of the products which requires giving them an identity. The distributed ledgers offer many different possibilities for food production and many other industries. The decentralization of data is one of the biggest features that the blockchain introduces to data storage which allows these systems to be more robust and scalable. Verifying that the inserted data is accurate is important and this task is done by the peers of the network as covered in chapter 2.1. The already stored data in the chain remains the same always since it can not be altered afterwards[8].

There are several issues with the more traditional and current methods in storing data with the supply chains operations[8]. With centralized options each chain member wants to have their own system[8]. This makes the already potentially complex supply chain network even bigger mess in terms of the used systems. With a decentralized system the other parties can be used to monitor each other to avoid fraud for example. Illegal fishing is one big problem too and this applies to seafood and even small-scale fishing. Both of these can involve mislabeling the product to increase its value[8].

Some farmers might use spreadsheets or similar documents to store their data currently[1]. This format is troublesome since it is not designed for sharing when necessary and these files could be lost or corrupted in the worst cases. The main purpose with this approach is to keep the required personal logs rather than collaborating with others. One platform which is shared with all of the participants in the logistics chain allows all of the members to gain information and value for their respective fields which is covered in Chapter 3.1.7.

With distributed ledgers, the stored data can be shared securely in the network

[1] `https://gofore.com/recoding-podcast-internet-of-farming/`

between different parties by making it available for all parties. Alternatively, the access can be limited to only selected parties if necessary since distributed ledgers support permissions. Centralized data storage can be tampered and monitoring it sufficiently is difficult[20]. Without blockchain, similar implementation would not be trustworthy since there is no way to properly ensure that someone from outside of the network or maybe even one of the parties in the network has not tampered someone else's data. People might seek personal gains by sabotaging their competition or they could boost themselves by modifying their own data. There are many logistical and information benefits[7] for sharing the data and it should be enticing for each party to share their data with others. However, this also requires the various parties to be more open which can be a major challenge itself.

Data is also important for the final customer since it allows checking if the product is genuine and its origin which enables safer and more informed shopping decisions. This could boost the sales of premium products since people tend to gravitate towards well known products and brands. Special foods like organic food and more environment friendly products have also gained popularity.

Currently there is not really a way for consumers to verify whether the organic food is what it says on the packaging since there is not any transparency. This should probably be mandatory for certain products at some point when technology progresses. The ideal situation would cover every single consumable with a trusted food system. With food products nowadays it might take weeks or even months to find the origin of the product which is way too long time. With the advancing globalization and development of food technologies, traceability and provenance are also becoming very essential parts of food safety[7].

Currently data collection seems to be gaining popularity everywhere, but the actual use of that data is not quite there yet. With good data, you can potentially utilize it later for analysis. This sets a high bar for the data quality since the

analysis is not very likely to achieve anything if the data is bad. Data recorded by humans can be unreliable so automating that process reduces possible mistakes and it should boost the credibility of data[20]. IoT automation generally offers several benefits including speed, trust and less manual work. As more data is accumulated, it can be mined for possible vital information. Noticing certain trends can help with business decisions and boost profits.

Various types of devices are needed for logging events during the production chain while ensuring that the conditions, like the temperature and humidity, are optimal. For example, monitoring important factors during transportation such as temperature for the goods that have to be stored in cold is vital, otherwise the products can go bad. Though the IoT measurement security can be questionable as mentioned in Chapter 4.2. Combining IoT and blockchain can maybe help solving several of these trust issues. Automation of tasks in general can improve the efficiency and the flow of the supply chain.[8]

Blockchain and especially the distributed ledger technology has a lot of potential in different fields for use such as pharmaceutical, automotive, finance, insurance, device management, distributed access and food[8], [21]. Any logistics related area is also a possibility like cargo management and shipping, not to even mention anything that requires or uses global markets. Blockchain excels in the immutability of the stored data so it should be good for tasks that require trustworthy data.

Blockchain helps with the complexity of the large supply chains by storing critical information in it and sharing it to the others in the network and by doing this the value of the products can possibly also be increased[21]. This method is more transparent than other methods that are currently in use since the information is shared in real time and it is not only stored in a private system. This information sharing should produce more value for products and the chains[21]. With blockchain, the supply chain resources can be allocated more optimally due to real time data

from the state of it and this could help with business process re-engineering plans by identifying possible issues[21].

In the best case everyone would use a single blockchain system and selectively shared their data with the other participants. This would lead to standardizing the information logging and sharing process. Additionally, this should benefits all members with faster queries on the blockchain[22]. Though there are some performance degradation concerns as more data is accumulated in the blockchain[23]. However, this should not be a major issue but this topic seems to have some disagreements whether this is a big problem or not. This highly depends on the number of members in the chain, the platform of choice, hardware, connectivity and the size of stored data.

Despite all the great potential benefits, blockchain is still not very well understood and all of the possible applications for it are not well known. Still, it is very promising for totally new applications that benefit from secure data storage and sharing it with different parties. In blockchain development the developers still need to focus on security aspects since it is not completely foolproof.[24]

3.1.3 Food and system security

From food security point of view, blockchain can provide multiple different benefits which provide information to certain parties. One of the biggest benefits is the transparency which is one of the main points in using blockchain. This way the consumers can get more information about the products that they use and this service also increases the value of the product. Desire for information among the consumers has been a trend for a while and it makes a lot of sense among the other trends like organic food, sustainable farming and more. This information could allow the consumers to check out the carbon footprint of the product if it is measured and added to the system or it could be approximated using the transportation data and

visualized.[24]

Currently popular storage methods like the databases suffer from several potential security issues including different types of cyber-attacks (e.g. SQL injection[10]). Another notable trend is database ransom attacks where the data is encrypted and after that you need the encryption key to recover the data in acceptable time. Databases are also vulnerable to single-node failure[10] where your host machine can fail critically, which halts your service and in the worst case you could even lose your stored data.

Authenticity of food is an important aspect for food security. The food fraud causes economic losses and risks for health of people. Currently many different things can be printed into the packaging without any proof for the customers such as the geographical origin, production method, processing technology and composition[24]. The most typical fraud is very likely the fake origin country of products. Changing the country to local increases the marketing value of the product so it is probably very tempting for some. This issue also depends a lot on the country and their monitoring process. Food fraud is not a major problem in Finland but occasionally these incidents do happen still[2]. Meanwhile in USA food fraud is a 40 billion dollar industry per year[25].

More premium brand food products can cost more, and the fraudsters can try to exploit this for profit[25]. With trusted storage, the origin and every step of the manufacturing can be verified, and food brands could use this to protect their products and their own public image. Genuine product stickers are the current answer for this which is very lackluster approach. More trustworthy tracking and origin verification could be a major selling point for local and exported food products.

It can be very hard to eliminate food fraud since there are so many things to

[2]https://yle.fi/uutiset/osasto/news/food_fraud_on_the_rise_as_production_chains_grow_longer/9568511

observe and consider[25]. Replacing the genuine stickers with QR stickers with identifiable information would be more ideal than the current trend. Another way to combat fraud is increasing the transparency of the production chain[25] which has been mentioned several times already. Currently most participants in these chains favor keeping their own data private instead of structuring it and sharing it to others involved in the production chain and the end customer. This approach puts a lot of stress and trust on third parties that monitor the quality[25].

This whole authenticity checking system would not only affect the end product. As it would enable all participants in the supply chain, with the ability to verify the authenticity early using the linked information in the blockchain[25]. There are many different types of food frauds and some of them are pretty much impossible to currently monitor and verify. For example, a fraudulent component of the finished product can not be detected when basic tracking is used[25]. However, things like this should be detectable when all fine details are logged to the system.

Blockchain technology is great option for implementing a transparent tracking system for food products. International products have especially great gains in many ways from implementation like this[25]. Combined with various IoT systems, tracking has the potential to ensure that the food that you find in stores is still fresh since it was transported in the correct conditions and its origin has not been altered. The origin of foods can be traced with other different tools like isotope analysis[25] but these tests take time and testing everything is unfeasible due to it slowing the supply chain even more and it takes effort and consumes money. These tests need to be cheaper and faster to gain more popularity[25].

The real time IoT monitoring can increase security since it also makes recalling defective products easier, as any party in the supply chain can act on the findings which means that the defective products will not be recalled from the stores. Sometimes these things can slip through and the issues are found out later, but still the

consumers could be made aware of issues as soon as possible. Currently local supermarkets might notify about issues like these on their websites which have limited reach.

For increasing security, physical attributes of the product can also be stored and used later for identifying and cross referencing the product. Machine learning could be utilized here to combat fraud and possibly reduce the time spent on the analysis problem. Verifying the physical product appearance with various sources like cameras and sensors could be very useful method in combating fraud[25]. Meat products like beef have very visible features for example depending on what they have been fed with but most customers will not notice those differences[25]. Verifying various claims and certifications internally should be also easier since the data stored in the blockchain either supports those claims or it does not[17].

Blockchain may not be fit for storing big files like the raw images for the machine learning applications. However, this potential issue can be avoided by storing the metadata from the images instead[25] and the pointers and checksums to the off-chain images. This approach causes some inconvenience, and an oracle system is required between the blockchain and other systems to ensure smoother operations[25].

3.1.4 Logistics and food waste

There are currently available many ways to monitor the quality and originality of various food items. But these methods and platforms are usually specialized so they can not be used to cover everything happening in the whole supply chain since everything is still separated[24]. With blockchain technology all the different parties can join and use the shared system instead of running their own systems. Some may not like the fact that they must rely only on a distributed platform instead of their own. For them, there could still be options to run private systems in parallel as long

as the blockchain based system remains in frequent use and intact.

Food supply chain has several involved parties in it including farmers, processors, transporters, traders, wholesalers, retailers and consumers. In a chain like this, the information asymmetry is a big problem. If all parties in the chain do not receive the same information, the results might be a market failure in worst case. Often the parties can focus and promote their good qualities and how those result in great products. This same task could be done with blockchain by promoting the good aspects such as transparency, efficiency and security[24]. By combining several technologies like the IoT, distributed ledger and possibly even various data analysis methods, it is possible to track and monitor various items efficiently and in great detail. This innovation can help to provide higher quality goods by improving the tasks in the whole supply chain.

On the logistics side, shipping and arrival times and all the locations can be logged to blockchain system using IoT devices. This makes tracing back the product much easier since all key locations should be logged to the system[24] and that information should be linked to the physical product. More specialized storage and deliveries may require certain conditions like low temperature which can be ensured using IoT devices to monitor these important variables in the real time and with this data we can send vital alerts if the conditions are not met. While monitoring temperature and humidity is not very complicated task itself, this monitoring system needs accurate and durable sensors that could be integrated with the blockchain for additional security and smart contracts which could be used for alerting the responsible persons early and the conditions can be adjusted to be more optimal. Smart contracts also have potential for decreasing the amount of needed paperwork with exported products for example.

The high amount of food waste is a global problem and it is not very ecological[3].

[3]`https://lovefoodhatewaste.co.nz/food-waste/the-global-issue/`

The waste can be potentially reduced with early problem detection using this tracking system. Ideally the problems can be solved much sooner which reduces costs and throwing away good food can be avoided since the whole lot does not have to be disposed if only some of them are not edible. Each party involved in the process obviously has several responsibilities which involves following good practices since they collectively contribute to the shelf-life reduction of the product.

According to some studies, at least one-third of food production is wasted during the entire supply chain process[4]. The largest amount of that waste is happening at the start and the end of the supply chain[26]. One of the discussed ways to avoid this is increasing the information sharing within the supply chain between the different stakeholders which helps the participants in making more informed decisions with order quantities and inventory allocation[26]. Constantly aiming to improve the food supply chain is very vital since higher quality goods are in rising demand and meanwhile the amount of people on the planet keeps increasing. There are also certain areas where people are malnourished and simultaneously some areas have major issue with obesity[26].

Also, certain food groups, like fruits, vegetables and bakeries, contribute more towards the wasted food than others[26]. This waste is ultimately unsustainable economically and ecologically so there should be plenty of good reasons for all food supply chains to approach better solutions[26]. The most common reason for the wasted food at retail is the expiration date of the product[26].

This issue is highly affected by the transportation speed, the ordered amount and the correct storage conditions. There is also a lot of paperwork required for delivering food products abroad which can slow things down. Pretty much all these steps contribute to the shelf-life of a food product. The common causes for these issues are the lack of communication, incorrect forecasting and poor management[26]

[4] `https://www.usda.gov/foodlossandwaste`

but luckily most of these could be improved using better information systems.

Lots of other things contribute to food waste and lack of recycling that involves the consumers themselves. Even recycling different packaging materials could get a lot easier for consumers with attached detailed guides for products which could be a great off-chain add-on for the whole system. Currently the various recycling symbols are pretty confusing unless you actually memorize them which is not ideal. People can often disregard them and toss everything in the general burnable waste if they can not tell quickly what the symbols mean.

Online shops could also help in reducing the high amounts of wasted food but there are issues that need to be solved first. The expiration dates of food products may not be currently available for online food products. Meanwhile in the local store you can check them before your purchases as much as you please, which is very valuable for consumables with expiry dates.

3.1.5 Utilizing DLT

Real time updates are important for a logistics monitoring and management so the chosen technology and platforms must meet that demand. As previously mentioned, sharing the collected data more openly is also valuable to the other supply chain participants. Centralized options have flaws that make them less suitable for applications like this, so this is where the distributed ledger technology comes in. Distributed ledgers enable trusted shared storage which can be permissioned to control the access to the stored data despite the fact that all of the nodes store that data.

Distributed ledgers enable the use of smart contracts, which are essentially self-executable scripts that are one of the big innovations of blockchain technology. These automatic programmable tasks can be adapted for various systems[21] that were not viable to implement previously due to lack of a trusted platform[6]. There are

many blockchain platforms currently available that can use smart contracts like Hyperledger Fabric and Ethereum. Depending on the implementation and use case smart contracts can also increase the efficiency and transparency of the business network. Automatic orders for necessary goods can be done automatically when certain criteria is met[6]. They can be utilized for reducing the amount of paperwork also since these contracts are formed mutually.

Smart contracts open potential vulnerabilities since the contracts are executed on the computers, which are part of the network, and these computers could be vulnerable to various attacks[6]. Trustworthy mechanism is needed for these contracts to be safe for widespread adoption. In Ethereum users can define functions and data structures for their contracts and then deploy those on the blockchain[21]. Typically, the contracts are formed between two different peers in the network. In the case of Ethereum, the contracts can communicate together through the Ethereum APIs and addresses[21].

Utilizing smart contracts in business applications has been a research area for years[21] and these same possibilities are still relevant today. These mostly center around increasing automation and optimization with the synchronization of data in the blockchain between different parties. This data can be monitored and used in several ways which allows increasing the value of the product[21]. This technology could also be used for enforcing legal contracts with the supply chain shareholders and their interests while reducing the paperwork[21]. Though there is one major flaw in the general adoption of smart contracts, and it is the programming knowledge requirement.

While distributed ledger technology has smart contracts, these computations can not do everything. For example, the machine learning methods for grain beef image verification can not be ran on the blockchain[25]. The results from such analysis can still be stored in the blockchain or in another system. Oracles for blockchain

are mechanisms that can fetch external data and add it to the blockchain system. These off-chain external data sources can provide and use various proofing methods to verify the acquired external information[25].

There is potential for reforming the supply chains based on the distributed ledger platform but there are still challenges in adopting these systems[21]. These include possible privacy and legal issues[21]. On the technical side lack of standards and protocols is another problem for now[21]. On top of these the implementation area can pose additional problems which usually will include the lack of understanding what is a distributed ledger, and why is it needed.

There are different types of blockchain implementations, so you have to pick the most suitable one for your application. Private blockchain implementations are more suitable for business-to-business applications where anonymity and competition can also be taken into account if necessary[21]. These private systems can only be joined with a permission which makes them different from public ones. For various businesses there is not necessarily any need to add any confidential data to the chain, like business secrets[21]. Private approach is suitable when you mainly want to share data with only specific people or parties in the network.

Private blockchain networks are still vulnerable to various attacks but to a lesser extent. There are lots of different consensus protocols available to ensure the trust in the network as mentioned in Chapter 2.1. Usually, they are a bit more specialized so public blockchain implementations have their own optimal choices and private ones theirs. Though several of them could still be considered immature since they have not been tested extensively.

With the Practical Byzantine Fault Tolerance (PBFT), which is another pretty common consensus protocol for private distributed ledgers, attackers need to control at least one third of the network[10] in order to modify it. Also, it is worth mentioning that there are some hybrid blockchain implementations which grab some

features from public and private implementations.

Currently it is very typical for the information in food supply chain to be separated into different platforms and methods which is not very efficient. Moving to a private permissioned shared ledger would make sense since those custom systems probably need lots of unnecessary work and the data sharing could be more streamlined. Private and permissioned blockchain systems have potentially smaller transaction latency than the large public ones[6] since they are limited and these networks do not suddenly explode in size. Also, it would make a lot of sense to include government authorities in these private systems for better monitoring, collaboration and increased trust.

Several of the chosen publications had suggestions and some early implementations for these food supply chain systems. The most flexible ones provided platform and hardware independent solutions which would not have to be tied to a specific device or a cloud service provider. Boxing yourself inside such services can be detrimental since many things can change with these platforms like pricing, the actual hardware, speed and support just to name a few. Your chosen platform or a required feature could even disappear in the worst case if the service provider decides to get rid of it. While this is not extremely likely to happen, it is still possible.

3.1.6 IoT and data storage

There is a room for automation and increased monitoring in logistics and this is exactly where IoT shines thanks to the current technology and its affordability. In fact, the potential of IoT devices in food supply chains was highlighted in European Commission Information Societies strategic research roadmap for more efficient, safe and sustainable future[27]. There are several potential issues that should be solved before widespread adoption since logistics chains are very critical areas to be implement properly.

Most IoT devices and systems related to them are currently centralized and this approach may have potential security issues. In fact, it is relatively common to see various articles about certain devices getting breached and after that being exploited for something like DDoS attacks. Sometimes even whole systems can get compromised and this has potentially even worse consequences. In secure storage the data needs to be encrypted and the database needs to be configured properly in order to avoid intrusions, leaking sensitive information and hijacking the control of the central server.[9]

Centralized more traditional data storage methods have faults that make them unfeasible for trusted tracking applications. These systems can not guarantee data integrity and availability. A single node failure is a possibility with a centralized approach which could lead to data loss[10]. These systems are also vulnerable to primitive attacks like SQL injection and data tampering[10].

Most centralized systems, IoT devices included, suffer from several security issues like remote modifications to the systems. This is where blockchain can help by securing the code change deployments[6] and improving the security of the whole system. Blockchain can be used to create distributed identities for devices and people. There is a lot of potential for using blockchain for security services such as access control, authentication, privacy control and confidentiality[9].

With decentralization these systems get more reliable and scalable[6]. Decentralized storage and device management architecture could help solving some of the mentioned problems by using the distributed ledger technology. In this case the whole system would be kept in order by the members[9]. All additions to it would be broadcasted through the whole network and the critical tasks that require consensus from the peers would also include that[9]. Blockchain additionally makes the changes easy to view due to the linked nature of blocks and it can also help in minimizing the costs of monitoring the server and its security. IoT and blockchain

integration is critical to get the most out of these technologies.

3.1.7 Gains for all participants

The data collection has benefits for the involved parties in the different stages of the supply chain[7]. This data can be used for the supply chain's benefit by analyzing it and optimizing the chain based on the results. Lots of data is being collected nowadays since it can be valuable later as long as it is high quality. This could also contribute to avoiding food waste by optimizing deliveries and organizing them better.

Reacting to issues early can avoid unnecessary spending for transportation for example. The data could be shared with the officials that audit the products to ensure that the regulations were followed correctly. The food supply chain can be often portrayed as a simple line with a start and an end. More accurate presentation would be a recurring cycle that should be aiming for various improvements for each cycle and gathering more information from each step should help with this goal.

The current centralized retail supply chains might not gain all of the benefits from decentralization if the product manufacturer and retailer actually owns and manages the whole distribution system and logistics in it by itself[13]. In this case using a decentralized system would mainly prevent single point failures and offer more logistics information. Data distribution and security are very important when creating a complete tracking system[16] and blockchain can be used to achieve these goals. The data in the blockchain is secured using cryptography so even though the peers have the whole blockchain stored, all of the information may not be necessarily available to them[16].

There are various ways to collect data from farms about crops and animals with various sensors and devices in great detail. While farmers mainly utilize this data for more optimal farming, some of that data can also be added to the blockchain

and linked to the finished product. Certain items are hard to track in fine detail though. Grains from a certain field could be mixed in transportation with grains from other fields for example.

IoT weather stations can monitor the quality of crops through the measured air and ground conditions[28]. There are lots of possibilities since so many values can be measured accurately locally, including: Wind speed and direction, temperature, barometric pressure, precipitation volume and rate, relative humidity, leaf humidity, ultra-violet irradiation and various soil details[28].

Remote data sources like satellites and drones can also be utilized for farming purposes since certain data can be gathered over distance. Thanks to increased connectivity options and small IoT devices being able to do several things, farming can move on to more smart agriculture. With the current timing with blockchain developments it would make sense to adopt a trustworthy platform for data storage, traceability and collaboration. In a system like this, the data sources would be identifiable, and the stored data can not be altered[6].

Data sharing with a blockchain based system can be much more secure and trustworthy than what is possible with a typical centralized platform thanks to the immutability and the permissions. Even though the peers might have the whole blockchain stored on their device, they can not access data that is not meant for them thanks to the permissions since the data is encrypted[6].

While centralized systems have contributed a lot in the development of IoT systems, they have flaws and the users can not be totally sure if the stored data is genuine since centralized systems lack transparency[6]. These traditional systems, like security systems, can not guarantee to preserve the data in the original state despite the use of various cryptographic techniques and their the best efforts. This can be a major issue in the future with IoT devices and their adoption to various fields[10]. Basically the blockchain as a platform should work really well with IoT

and it has potential to increase the security of IoT devices which is necessary since currently there are lots of vulnerable devices with connectivity out there.

Usually new technology adoption takes quite a long time and blockchain is still in its infancy. However, several food suppliers, transportation sector and IT companies around the world have already started to work on blockchain platform solutions with their various partners to solve their pressing inventory, quality and tracking problems. These solutions vary from the improved food supply to shipping, tracking and logistics improvements[7]. There is a lot of focus especially on the logistics side of the supply chains. Another typical goal with these systems is to reduce costs[7].

IoT solutions are being deployed in many areas, optimizing production and digitizing industries[6]. Most of these simply could not be implemented before since the other necessary technology, like good remote sensors, were not yet available. But they are available now and more integrations are yet to come.

Since blockchain is in the early stages, there are still several concerns like the scalability of it with very large supply chains[14]. There are plenty of challenges for developing applications with blockchain currently like creating a general platform for different supply chains[7]. The costs for participants should remain reasonable for even the smallest parties to further boost the adoption. Luckily most IoT devices are pretty cheap, though there are more expensive options available too, which might have better accuracy.

With distributed ledgers, physical items like food products can be identified with tags or with the stored information like an image[14]. There are several tagging methods already available that can be used to link digital identities for these real world objects. For example RFID is commonly used for tagging animals. Bar codes are available on every product at the supermarket and there are several other identifier options too like QR codes and batch numbers. These identifiers and the past tracking history gives the product a distributed identity. Certain items like

crops can be harder to track in fine detail but this should not be a major issue.

For example beef can be tracked using RFID tags from farm to slaughter which is one possible solution to previously inaccessible traceability records. There are also flexible data logger tags available nowadays that can be attached to items like wine bottles to measure the light, humidity and temperature of the environment. These tags store the measurements locally during the transportation to supermarkets and this collected data can be read using a phone.[14]

While the blockchain technology provides unique features, advantages and solutions for known problems with data storage and the food supply chain management, there are some limitations. These include the infrastructure requirements for devices and the nodes that participate in the blockchain. The transaction rates have to meet the needs of global supply chains which basically means they have to operate fast. This can be ensured with good connectivity and utilizing capable devices as nodes. Though there might be less reliable connectivity, or maybe even really bad, in certain areas like more rural areas, where fast and stable physical connections are not an option, which makes this more challenging to achieve. Luckily wireless connectivity technology has been progressing forwards at a nice pace to achieve greater speeds and better coverage.

With smart contracts automatic instant payments on various deliveries with no unnecessary middlemen are possible. Getting a fair deal can be hard for farmers in certain countries and currently they might need a middleman for selling the produce. This usually results in the farmers losing a cut from the price and at worst the farmers could be cheated. With the sharing aspect, the seller, item, amount and price could be shared with the network to provide others with more insight. Food markets are currently mostly occupied by large companies that make agreements with farmers for their services and goods. Blockchain could change this in the future, and this could lead towards more independent farmers or even more popular

and efficient supply networks.[13]

Some potential performance issues with blockchain have some solutions too with different approaches that are being researched. One such technique is sharding, where the entire blockchain network can be split into smaller sub-chains, with each having its own state and transaction history. Another idea is to build multiple child chains apart from the main chain to process some of the transactions separately and periodically settle their states with the main chain. Running multiple parallel chains can also improve the throughput and transaction speed. In addition to the throughput, indeterminate latency over the Internet and poor connectivity in certain areas can lead to unacceptably long transaction times.[7]

Generally, as more information is stored in the blockchain, the nodes require more and more resources to operate optimally. Very large chains may also suffer from decreased performance and this affects most of the operations on that blockchain like transactions[6]. The whole chain synchronization for the new members also takes more time when there is a lot of data[6]. These major hurdles need some good solutions before blockchain systems can truly shine in various real-world applications.

A very fundamental problem with the complex supply networks and their applications is which piece of information is relevant enough to be stored in the blockchain itself[7]. Some of that information might not be relevant for the goal so it should be stored elsewhere[7]. Currently, for more optimal performance, everything should not be just stored in the blockchain. Another issue is getting the tracking information of various raw materials and verifying its quality[13].

Information technology is constantly changing and new faults with varying severity are found out in pretty much any software nowadays. Luckily with the increased connectivity these issues can be fixed after initial deployment. Even blockchain applications need updates and changes just like other systems. Blockchain systems can still be updated and optimized after the initial deployment using soft forks and

hard forks[6] which are blockchain terms for essentially minor and major updates to the system.

Hard forks can contain big protocol changes, which may lead to the network splitting in two if there is a major disagreement in the protocol or the state. Ethereum and Ethereum classic exist because a thing like this happened. With soft forks, majority of the peers can force minor protocol or code changes for supporting new transactions. Majority of peers need to accept these changes for them to pass. Soft forks are always compatible with old blocks of data.

Potential privacy related problems in blockchain are heavily related on the chosen implementation. Permissioned private networks with restricted access are a much more strict with access than public permissionless networks. Therefore permissioned blockchain implementations are more suitable for many of these actual real world applications. Only peers that are participating in the supply chain are wanted as nodes and the participants should not be able to read everything that is stored in the blockchain. There is always the option to store the sensitive data off the chain too[6].

3.2 Conclusions

In this study several potential benefits were highlighted among some of the current problems. Blockchain technology has great potential for innovative trusted platforms in the food industry. Most notable cases for this are the food supply chains and other supply chains that require high trust and monitoring. Blockchain's decentralization can provide new features that are not available on centralized options.

The whole logistics system of the supply chain could be overhauled to promote more collaboration with the other stakeholders in the supply chain. This is where the distributed ledgers come in. With private shared ledgers every node in the system participates in the upkeep of the system. While the performance of blockchain can

still be a major concern, transaction and query times should remain reasonable.

Doing product origin checks in a few seconds is a massive improvement compared to potential several days or even weeks of waiting for the results with the current separated private systems. The performance optimization is a large topic that was not covered fully due to the scope of this work. In terms of blockchain security and vulnerabilities, some of the most known ones were mentioned but due to the massive size of this topic, the details are out of the scope of this thesis.

The main targets for utilizing the blockchain for food products are innovative companies and sharing information with chain members. Customers can also be seen as targets since people generally want to know more about the products that they buy. Also, this technology could get rid of possible fake products since the packaging is now unique for each product and this makes it hard to copy. Just copying the QR code is also very unfeasible since the products expire fast in the food industry.

There is also room to innovate and push the food products forwards with trusted tracking and many other new technologies like smart packaging which could also be integrated with the blockchain system itself. This could be used to provide the consumer even more information about the product that they purchased even at their home. At that point the storage conditions affect the expiry date a lot and it could change on the fly if necessary and notifying about approaching expiry date could help with avoiding wasted food or even possible illnesses from expired food.

Gathering data from consumers after the purchase could also give very interesting insight to the producers. What are the most common storage conditions, when the packages are usually opened and other small things like these could help with packaging design and other logistics decisions in the future. There is a lot of potential for various data analysis methods in the future.

4 Blockchain for a food network

Currently most of the food supply chains around the world are black boxes for the consumers. From their viewpoint, this is the opposite that the food supply should be for ensuring safety and increasing trust. There are several different issues related to this lack of information like the food adulteration possibility, delayed responses for issues and the higher possibility for foodborne illnesses[29]. Some of the common food adulteration targets include honey, oils, meat products and seafood for example[29].

These issues are found occasionally and after that lots of food is typically recalled or thrown away since lacking information leads to disposal for safety. The general trend after that is a major drop in sales of that food product type for a while. This usually applies to the other similar products even if they do not share the problem. This could be avoided with a better, more trustworthy, tracking system for food products. The inefficiency of existing food supply chains also contributes to the food waste[29].

These supply chains can form very large and complicated networks. This can cause lack of communication with different parties involved in the production chain. Some of the materials used can also be outsourced from which complicates the network even further. Typically, each stakeholder focuses on their own part in the supply chain and this approach does not promote the needed transparency. A stakeholder doing the optimization poorly can lead to excessive or deficit inventory

and it can increase the costs in worst case[30].

Shared information can help with some of these potential issues. For example, sharing the market demand with the stakeholders can help in making better decisions. In some cases, the provider can manage the chain which places trust and pressure on the manager so it has flaws[30]. Another step forwards is synchronizing the supply chain which is a very coordinated task and this puts even more pressure on the management[30].

And finally, there is the decentralized supply chain concept which focuses on sharing data that is kept trustworthy by the peers in the network. This implementation does require lots of technological investment but the potential payoffs from it should justify it. Not to mention a system like this could be also used for other things like sharing some information with consumers and providing access for relevant authorities. It is not just about the optimization of the supply chain.

4.1 Utilizing new technology

The evolution of supply chains involves adopting new technologies that enable new strategies and growth opportunities for the organizations involved that were not previously possible[30]. Blockchain removes the need for third party monitoring and intervention thanks to the trusted nature of the distributed ledgers. The use of DLT promotes collaboration among the participants and it offers advantages for them. There is potential for the chain management to improve with more information about it.

The most notable bit of information is the history of the product, which can be used to check all the steps that it went through and where it originated from. This information can be accessed very fast at any time like during shipment or at the local supermarket and it can be used to save time and money instead of delivering bad batches of products for no good reason. Cold chain for certain items needs

active monitoring and trusted data storage for the measurements which enables early detection of failed batches[30].

There are several areas that can be improved but they can be boiled down to three key categories: process optimization, data visibility, and demand management[16]. All three of these can be improved using blockchain and IoT for a trusted tracking system with information sharing. Distributed ledgers, which use blockchain technology, can be used to implement these systems even for complex traceability tasks in supply chains[16].

There is plenty of demand for flexible supply chains, which is usually driven by business goals[16]. Enhanced customer satisfaction and retention are important, and these goals require a good supply chain to simplify it and provide smoother functions. Identifying the correct technology is important to reach goals like these[16]. A new logistics system that enables faster tracking also enables faster food-borne illness containment, early detection and increased trust[7].

Other potential improved areas can include customer service, information gathering, storage capacity and real time work[30]. Optimizing various costs for transportation, delivery and maintenance would be ideal for a shared system like this[30]. A distributed ledger could be also used to solve double marginalization and information asymmetry in various supply chains. It also enables sharing trusted data in real time with selected peers[30].

Several large IT companies, including IBM and Microsoft, are investing towards blockchain development and big data in general[30]. DLT has lots of potential and it could alter the food product industry with the trusted distributed data storage. There are advantages that companies can gain from using collaborative technology like distributed ledgers though currently adapting it for specific use cases is still very experimental and limited. These positive impacts can be measured in many ways, including the costs, speedy waste mitigation, transportation, processes and

overproduction[30].

There are some drawbacks to adopting blockchain applications since it can still be considered brand new technology. The most obvious one being the costs of creating such applications. On top of that DLT is still very immature for now but it has potential for improving business. This decentralized method of storing data competes with existing systems with the new features that it brings on the table as mentioned before.

Traditional databases that manage information in alterable tables of columns and rows have a big challenge in the security management and reliability of information[30]. Perhaps the authentication for some of those is going to center around a blockchain platform in the future. This could increase the security of databases. DLT enables potentially the next evolution of supply chains and logistics[31].

Use of DLT could be essential in the future to be able to compete in global markets. It could become necessary if this technology becomes very common, well known and even mandated. It is suitable for the global transformation, that many companies are facing, and this could provide a good kick start for exporting products in the highly competitive areas. The DLT can help in improving the quality and safety of agri-food products thanks to its features. This should increase the reliability of the goods along the chain[30]. This distributed approach may also require some transformation on the company culture and administration side since being more open and sharing things is one of the main goals with a new distributed system.

The collected information could be used in data analysis to forecast trends which can help the the supply chain operations[19]. The data collection trend has already started in several fields and adopting it to the food supply chains also makes sense. With large amounts of data this use also encompasses big data which is essentially all about grabbing data from everywhere and combining it and using it to create value. Big data analysis may need some more specialized methods since more normal

methods might be very slow in extracting new information and value for the parties involved in the supply chain[31].

There is potential for logistic improvements by sharing information and automating tasks. This can potentially reduce unnecessary paperwork and other simple tasks so that time can be spent elsewhere. Though there is an issue with adoption for these systems since several companies seem to favor more simple systems[31] which means they will not get the full benefits from using IoT devices. It is understandable that the scope of a complete food tracking system can be quite large. This is probably why most of the current implementations are a bit lacking in several ways.

Big data has a lot of potential to provide competitive advantage and unique opportunities to global companies[30]. These benefits mostly center around the increased collaboration in the supply chain like better inventory management and more aware administration which helps with the performance of the whole supply chain. Currently various global supply chains suffer from their complexity and inefficiency.

Improving the whole supply chain, or even parts of it, is a challenging task without unbiased information about how it functions. Without the big picture it is very hard for anybody to make well informed decisions. More likely scenario would be just claiming that everything works well based on recent events but there could be room for improvement. On top of supply chain improvements, several other things could be observed in much better detail including the plant DNA. This data could be used for various improvements to farming, which could include the entire crops' approximated life cycle and the produce[6].

4.2 Internet of Things integration

IoT devices are typically low power automated devices that started to emerge quite a while ago for automatic measurements, remote control and many other similar

tasks. IoT allows, for example, very inexpensive way of monitoring the temperature and CO2 emissions constantly using the integrated sensors. These measurements are usually stored in a centralized database like MySQL, MongoDB or PostgreSQL. The data storage can also be done with blockchain based systems but the security of IoT devices can be troublesome currently. The whole point of using blockchain is to store trustworthy data that can not be edited later so we need the real data securely from the devices. This can be problematic since there seems to be no standard for ensuring untampered IoT devices and data at the moment.

IoT devices can generate large volumes of data over time and they typically require some form of wireless connectivity and power for long periods[6]. These devices typically have limited hardware that specializes them in certain tasks to limit the power consumption. These limitations may include other things like limited memory, computing capacity and communication speed. This creates several challenges[6] but it also keeps the cost of creating these devices low which makes them very affordable. IoT devices shine in automated monitoring and performing simple monotonous tasks. The biggest advantage with most IoT devices is arguably the low costs and the possibility to collect large amounts of data.

There are already billions of IoT devices out there and that number will keep rising over time. This raises some concerns for security issues related to these devices. Some IoT devices do get compromised for various reasons, ultimately due to lack of security updates to them. This creates lots of unnecessary electronic waste over time since the chances of users having the knowledge and means for doing updates themselves are very low. Decentralization and heterogeneity are the two major characteristics of IoT[10] so blockchain should be very suitable for IoT integration.

IoT not only faces a large number of devices (also referred to as nodes) but also growing demand for capacity, as numerous devices sense and collect data[10]. With various IoT networks, there are large amounts of nodes present which makes

decentralization essential for the network since the various IoT nodes collect data in a decentralized manner in different locations[10]. The wireless connectivity can be spotty depending on the location of the device. For example, moving vehicles can cause lots of connectivity issues compared to stationary locations[10]. The connectivity issues can lead to certain partitions of the network being unresponsive or disconnected for long periods of time[10].

IoT is very unique with the ability to operate pretty much everywhere which ultimately leads to more unique potential threats[18]. Unattended devices are problematic in terms of security and privacy since it makes them vulnerable to harm from several different sources[10], [32]. Physical attacks are a pretty big concern on top of the remote threats. Some of the incorrect system configuration might even leak the location of the device[18].

The collected information can be very sensitive for certain parties. Because of this you might want to share it with only selected few which can be a challenge depending on what kind of system is used. Internal sharing might be fine normally but sharing the data with selected external parties can be somewhat risky as the data could leak. This is where the permissioned private distributed ledgers come in.

A big problem with the current centralized data storage is the trustworthiness of the data[32]. How can you be totally sure that your, or even some other party's, data is intact when it reaches the system? Physical IoT devices are not typically tamper-proof. There are many potential flaws that blockchain could solve but the human factor that can cause mistakes still remains as long as these systems are made for humans.

Currently the collected data can be stored, forwarded and processed in many systems and this increases the risks of tampering and forging of the data. By having one decentralized platform for the entire supply chain, you are essentially making collaboration smoother since the data can be shared in more trustworthy fashion.

Everyone using their own centralized data storage method does not guarantee the integrity of the data which affects the safety and trust of the whole system. It is possible to use both, databases and blockchain, to form a trusted platform. Oracles are one option for interacting with off-chain systems since they can fetch external data while aiming to keep the integrity of the system.[10]

Combining blockchain and IoT has potential to solve some of the issues with IoT like the security problems that many devices are facing, but the implementation is not easy[15]. There is some potential for lightweight blockchain systems that could provide more security and privacy for things like smart greenhouse farms[15]. IoT gateway machines as blockchain nodes could be another option even with the low-power IoT devices[15] since that moves the blockchain processes to a more capable machine.

Running the full node on limited IoT devices is not currently feasible, but there is a limited node option available on some of the distributed ledger platforms, which does not require storing the whole blockchain. But still, maximizing the longevity of the battery is probably more desired than having the IoT devices as less useful validators. Relying too much on these limited nodes could also compromise the network in the worst case and their limited networking might slow down the the operations. So overall they might not be worth the effort as nodes in the food tracking process but on the other hand new security solutions could be useful.

A distributed ledger for the whole supply chain could increase the collaboration between different parties involved. This could be very beneficial for authorities and government agencies involved with the food products[6]. Having a system that guarantees data reliability would allow the businesses and authorities to share information securely with each other.

Traceability is already required with certain types of food already in certain regions of the world[6]. European Union has strict regulations for food products and

over time these regulations can become even more strict. Pork supply has already strong regulations that require recording information about the raw materials used for feeding, used treatments and transportations[6].

Increasing the tracking coverage in food supply chains can be a big challenge. One large food producer chain could have thousands of suppliers and this causes a major need for digitization and seamless systems. In the current state of IoT, improving and expanding it also requires better standards and protocols[6]. The integration with blockchain can be a major challenge since the collected data needs to be trustworthy and the IoT devices are mostly meant to be unattended.

IoT devices can generate large amounts of data even in a short amount of time which can result in lots of transactions for the blockchain system. Some of the current blockchain implementations can only process a few transactions per second which can lead to bottlenecks for the system[6]. Luckily, all of the collected data is not important for the food safety and origin system so some of it can be excluded if necessary.

Compressing the data could be another solution or even storing the data off the chain in some cases[6]. Consensus protocols that require mining, like Proof of Work, are not suitable for these limited devices[6] so alternative consensus protocols are required. In the worst case, the consensus mechanism may lead to bottleneck situations with large amounts of data.

Pretty much anything can have an identity in these systems including users, devices and items. By setting up IoT devices along the supply chain, the collected data can be stored in the blockchain and linked to a physical item using identifiers. For physical items the easiest way for this is to use available tagging methods. Food products already use bar-codes and serial numbers since they are required at least in certain countries and areas. Because of this, using these as an identifier would be ideal but there are also other relatively cheap and efficient methods such as NFCs

and QR-codes.

With a more secure IoT system, the generated data should be reliable and unaltered before it is saved in the blockchain system. The physical devices can have various issues including hardware failures and vandalism. Since the devices have connectivity, there is a threat of eavesdropping, denial of service attacks and other networking related threats[6]. IoT devices are currently infamous for the general lack of firmware updates that fix security holes, so new systems that enable remote updates are essential[6]. With blockchain IoT devices could have their own distributed identities which can be used to mitigate security issues.

Due to the storage limitations IoT devices are not able to store all the ledger's data due to limited storage capacity. Over time the ledger can get too big for storing in IoT devices. There are some possible solutions that can help with this issue. One of them is the concept of partially editable blockchain[10]. Food products have expiration dates, so the stored data becomes redundant after a while[10]. This data could be moved to alternative storage system and removed from the blockchain system to improve the performance and lower the requirements for nodes by decreasing the amount of stored information[11]. More powerful computers acting as IoT gateways is another option to solve the IoT problems with blockchain. In this approach the more capable machines act as blockchain nodes and the IoT devices communicate with these gateways.

The editable blockchain concept is kind of against the immutability of the blockchain[10] but removing redundant data makes sense with food products. So, depending on the use cases this could be very useful and a clever thing to do. Also, if the rules for deleting older blocks are done well and with care, the important trust factor should still apply despite these modifications. The security aspect needs also some attention, which means that the conditions for editing need to be secure and all edit actions should be recorded on the chain, so the chain remains reputable[10].

The used devices should be designed for the intended environment which might be very wet or cold for example and the location needs to be optimal[28]. Some measurements, like leaf humidity, are going to be completely wrong if the device is not in a suitable place. In addition to IoT devices, drones can be used to collect data like high resolution multispectral images, which gives information about the status of the crops[28]. This data can be used to gather information about the lighting conditions, lighting angles and the synthesis process[28]. Some additional data can be collected with satellites to provide even more information about the crops and farmland[28].

4.3 Supply chain

Currently supply chains have problems that a IoT and blockchain based system can solve and there is potential for further improvements later down the line as the coverage is expanded and more data is collected. Several things on the packages of food products can be forged. These wrong labels can include incorrect ingredients and locations for example. Food frauds and scandals are relatively common around the world and it is a major problem[8]. There are also several other sources for issues like illegal fishing, polluted areas and more, which could be reduced a lot with better and more open tracking for food.

The whole product chain starts from the local farms in the best case. The use of a distributed ledger would not be so useful if the whole production chain is not actually participating in it. The main point is to make the whole chain as transparent as possible so the consumers can view the steps of the products. Sharing information with other supply chain members could be very beneficial since the supply chain can be seen as a constant cycle that improves based on earlier cycles and findings.

As the global competition increases, smart agriculture and farming becomes more important for the business just to stay competitive with prices and quality. Luckily

there are different devices and technologies available for monitoring in real time pretty much anything like the soil and weather. On top of those, certain tasks can be automated using the collected data like the irrigation tools. The general trend with food seems to be that consumers want higher quality food[28] and using these tools can help to meet that demand. So, there are technological, ecological and financial incentives to adopt and use new food technologies[28]. Blockchain and IoT has disruptive potential for these markets due to the decentralization and smart contracts[28].

For the farmers the amount of storage status for resources like grain, seeds or even fuel could be saved to the ledger and when they drop low enough, those items could be automatically ordered from their choice of supplier using the smart contracts. This automated inventory control could be used in any part of the food supply chain. General crop variety and their growth time and weather conditions could be very beneficial information to share with other nearby farmers[7].

Agriculture is generally very dependant on the local climate and ecology[28] so collecting data of it makes sense to get a better understanding about the changes in it and how it affects the crops. The suitability of a location for specific crop variant and its water and nutrient consumption and other growth conditions can be measured using sensors[24], [28]. The health of farm animals can be monitored with IoT devices also.

For the entire supply chain, the responsibility of the tracked items always moves on to the next supply chain member as the items move through the supply chain. Each event in production chain should be logged to the system. In optimal tracking system this would include the location and timestamp for each event. To make things more personal, everyone who does something with the product could also basically stamp the product digitally. The use of a distributed ledger could be used to reduce the amount of needed paperwork.

With transportation of the goods, the conditions are the key so things like temperature and humidity can be monitored in order to add them to the system[7]. Some key events like the transportation details should be logged which allows early problem detection and actions in case of possible damage during the transportation or even previous steps[7]. Meanwhile the processing facilities and storage mostly do the same basic things including verifying the condition of the received goods and checking the previously stored details[7]. The improved tracking would reflect the current state of the whole supply chain which could improve the management.

Consumers gain more information about the product if every step of it has been logged to the distributed ledger and made available for viewing. This information could include the batch number and expiry date as usual but with the distributed ledger technology every product can be tracked in much finer detail. The consumers get better and safer products since the origin can be checked[30]. Some local food products may already mention in the packaging which farm produced it, but this is not verifiable and there is no way this approach would work with exported products.

There are different technologies that can be used to improve the food value chain in several ways on top of blockchain. Nothing really stops these additional systems from also being integrated to work with the blockchain data storage system. Modern technology brings new tools for solving problems. These include advanced analytics, machine learning applications, automation for simple tasks and virtual assistants. These can help with the increasing demand for quality food products which is a major challenge with the increasing urbanization.

Big actors of the supply chain can attempt to optimize the whole product chain to a new level with the increased information flow. This optimization requires investing and data analysis but the competition is heading towards this goal. Several companies are interested in collecting data since mining it can bring benefits. Smaller producers might not get so much out of utilizing a system like this unless they join

a shared system with others. Though the most optimal case could be that everyone producing food would join one big, distributed food platform.

4.4 Current innovation

The use of blockchain based systems in food and supply domain is still pretty new concept and many are trying to figure out how to implement these well and spread it to the whole logistics chain. Information about these early implementations is limited but some have lots of details. Some of these blockchain based systems for food tracking and logistics are already implemented and in use to some extent. The more public ones have many things in common with their own requirements and area specific quirks. One of the biggest benefits from a system like this is that it can pretty much guarantee the food safety[15].

However, there are potential issues for companies who aim to implement a blockchain based system. One of the biggest is the data sharing policies between different parties involved. Sharing as much as possible should be more beneficial for both parties than limiting it and hindering the possibilities. The most open chain may become the most advantageous over time thanks to the data sharing. Globally various startups have taken the spot as problem solvers and innovators using available technologies along new business models[31]. This typically involves creating standalone projects or merging the new solutions with existing systems from bigger companies.

There are plenty of ideas for applications using blockchain in logistics and their architectures. These early systems mainly specialize in a certain thing, so there are not that many systems or suggestions that cover everything. One general option would involve each participant in the chain to run one device as a node in the blockchain[15]. Then all their devices are connected to that portal device and the data from them is stored in the blockchain. These include the IoT devices and

traditional Enterprise Resource Planning (ERP) tools and methods.

To make the data easily accessible to customers and the other parties involved in the blockchain, the data can be made easily viewable using common devices like phones. Phones can act as portals or even as thin nodes in the blockchain[15]. The nodes are connected to each other via peer-to-peer connections and these networks can contain several types of nodes as covered in Chapter 2.1. Full nodes have all of the features and thin nodes are limited.

Trusted agro-food tracking for supply chains is very important for food safety. These traceability systems typically utilize tagging techniques which link the physical product with the digital information and that information needs trusted storage which can guarantee data authenticity[15]. Pretty much anything can be tracked with different tagging tools[15].

Adding the relevant data through the supply chain to the product should be mostly done automatically to avoid mistakes. This collected information can be very useful to even farmers who currently may lack information where their products end up, the quantities and how popular every item is. The data can be exposed to the customers easily through their own mobile phones or computers.

With the collected data, we can start to use big data analysis methods. These can include graphs, other specialized methods and predictions based on the data. This can provide the business various competitive advantages over other competitors. Essentially new knowledge is dug from the data mass that is not possible unless you have a lot of data available.

Currently most of the applications seem to focus on their specific interests and that is typically used for marketing. Arla milkchain has the ambitious aim to be the most transparent milk chain in the world[1]. This is a very common pilot imple-

[1] https://www.arla.fi/artikkelit/arla-milkchain--the-blockchain-for-more-transparent-milk-production/

mentation with a heavy marketing focus since this system is only used in a single farm and it focuses on giving the consumers more information about the milk that they buy instead attempting several different things. The whole system could be much more in-depth if it also included the logistics management. Still though, this implementation does increase the trust of consumers by making the productions chain more transparent, which is a great initial goal.

There are also some other more known implementations like the Walmart's mangoes where the shipments with pallets of mangoes are tagged with numeric identifiers. The status of them is updated on every checkpoint using those identifiers from farmer to the store. Thanks to this system, it was possible to check the day the mangoes were harvested, the location, the pesticides used, other important information and various other timestamps of the transportations until it arrived at the Walmart store[16]. This also reduced the origin tracing of these mangoes to a few seconds from multiple days, which used to be a major problem. IBM has also participated in pork tracking trial in China with similar goals that Walmart has with the mangoes.

In addition to mangoes, Walmart has also conducted several trial runs with IBM for tracking pork in China[7]. There are also several different implementations from other companies for tracking food, including fish[15]. These can be pretty much any fish whether they are from sea or fish farm. Each fish is tagged, and the logistics data is attached to that identifier in the system just like in any of these applications. With these tags on each fish, the information can be accessed at any point of the supply chain including the logistic center, retail shops and restaurants[15].

BRUSCHETTA is a blockchain-based application made for tracking and certifying Extra Virgin Olive Oil (EVOO). Just like most of the blockchain based production chain tracking implementations so far, this system monitors every step of the olive oil production process from plantations to shops. The collected information

from each step is then stored in the blockchain. The main goal with this project is to give the customers the access to the data collected during the production[4].

In addition to this, BRUSCHETTA uses the gathered information for estimating the quality of the final product and verifying its origin[4]. EVOO is one of Italy's emblematic products and at the same time it is one of the most falsified products[4] so tracking the origin is necessary. The production of EVOO and other food products in general involves multiple industrial parties with their own objectives[4].

All this could be implemented with normal databases but they lack the immutability and trust which are key parts of this application. The source code for BRUSCHETTA is publicly available on GitHub for viewing[4] which is also a big plus in terms of trust for anybody that would use it since people can check the code and verify what it does.

Rapid urbanization and increasing population have caused the management requirements for food to rise. To meet these rising standards, we need various new solutions and with those, the living conditions of people can be improved. Smart agriculture is a key part of the this. By adopting new technology, the food production process can be improved in many ways and more sustainable growth can be achieved[4]. These additions could even raise the prices of more premium genuine products thanks to the added value and maybe allow better online food shopping since the origin information for products is available.

Traceability is already enforced in certain areas, like the European Union, by law[4] and that is one of the potentially best use cases for blockchain systems. Originality checking for food products is valuable for consumers since you currently just have to mainly trust what the packaging says. These improved systems could reduce fraud and even potentially reduce the large amount of wasted food.

In Finland food products with unknown origin are thrown away when they are noticed since, for example, unknown meat poses risks. The chances of this hap-

pening would be much lower if everything was tracked with the necessary details. These tracking requirements could become even more strict down the line which can pose lots of problems for producers. Luckily technology can help to meet these requirements.

BRUSCHETTA uses Hyperledger Fabric for their implementation with heavy focus on the optimization of the blockchain performance through an auto-tuning mechanism in case of high loads[4]. In this application, the users are split into endorsing peers and orderer nodes. With this approach the permission system is used to make certain nodes able to only generate new transactions and read the ledger history[4].

With a permissioned system like this, everything stored in the blockchain does not have to be available for everyone in the network even though all of the full nodes do have that data stored. Additionally in BRUSCHETTA, the endorsing peers are responsible for verifying transactions based on the pre-defined endorsing policies, which are rules that define necessary and sufficient conditions for valid transactions, for the node that generated the transaction[4]. Finally, the orderer nodes are users that are responsible for ordering type transactions, grouping them into new blocks, and executing the consensus protocol[4].

BRUSCHETTA uses IoT devices for automatic quality control and monitoring of the entire production chain. IoT devices grab the measurements using sensors and operate with the blockchain system[4]. This enforces certification by tracking the product from plantation to the shops. One of the main goals is to allow the consumer to view the trusted history of the product[4]. This application could be expanded to include more parties with the data sharing in the whole production chain to increase collaboration. This approach could create even more value for all members from using this application. This information could be valuable for optimizing the production chain for example.

The farming section of the supply chain has many things that affect the quality of the olives like weather, pollution, used chemicals and the soil along its chemical properties[4]. All of these factors can be measured multiple times periodically during the farming process with IoT devices and the produced data can be included in the olive farming profile. Similarly harvesting has its own key factors that affect the quality of olives such as the time period, harvesting methods and time spent in the storage[4].

The transportation of olives from the farmers to refining is a critical process in this supply chain[4] and it must be monitored to keep the goods fresh and in prime condition. The temperature during the transport is very commonly required to be within a certain range, and it should be periodically monitored via temperature sensors[4]. Luckily nowadays the devices for these tasks can be very inexpensive to acquire and easy to install.

The olive refining process is the most critical part in the EVOO supply chain[4]. This process contains the various tasks to produce the olive oil where the temperature is again a key[4]. All of the temperature measurements are collected during the transformation process and packaging. The stores which are the last step in the chain do not add any data to the blockchain in this implementation.

During all these phases of production the collected data is stored to appropriate profiles that group the data[4]. The main goal of this system is the ability for the seller and customers to check the whole supply chain of a single EVOO bottle. This is done via a web application which reads the blockchain transactions and displays the entire history of the specific EVOO bottle[4].

Wenda is pretty similar project to BRUSCHETTA but this time the system is made for wine so its goals center around solving issues related to the wine supply chain[31]. With this system however, there is more focus on analysing the needs of various stakeholders in the wine sector along with implemented IoT and big

data analytics services and solutions[31]. The main goal here is that the refined information can improve the logistics system, and this gives competitive advantage in the business[31].

There is also a Hyperledger Sawtooth based system for egg tracking[17] that uses scannable codes. With this implementation, some analytics about the consumer behaviour is collected on the information page like the scan rates, time spent and unique users[17]. The possible use cases for distributed ledgers for businesses are pretty much endless and there is still more room for more elaborate systems.

5 Trusted food network

Fully digital blockchain applications and solutions have already gained popularity around the world but the actual real-world applications are not quite there yet. There are already several suggestions for architectures of such systems in various publications and some pilot projects exist. Typically, the pilots mainly focus on certain feature and disregard other important parts of the system. These systems could also attempt to include more business-related features on top of the desired transparent supply chains.

The goal with a trusted food network system is to include at least all of the major contributors in the supply chain as nodes in the private distributed ledger. This would exclude some of the minor raw ingredient providers to reduce the complexity of the system. All the production steps would be logged into the system and linked to the product using identifiers like QR codes. These QR codes allow anybody to view the previous events of the specific item at any phase of the production and with the finished product.

By adopting distributed ledgers as the storage platform of choice for the food production industry, current methods, flawed stages and processes in it can be streamlined to achieve efficiency. This goal can affect positively in different places in the supply network and it promotes more collaboration and sharing with others. It can help with the food waste by getting food products in the store shelves as fast as possible to maximize the shelf life. Currently big companies can form very big

and complex supply networks which can be a big issue for tracking coverage. This coverage can be increased relatively easily using various IoT devices.

Food products come with expiration dates, so the stored data becomes redundant after a while since the products expire eventually. After that the data could be moved to alternative storage system and removed from the blockchain system to ensure the system stays efficient. Some products can be frozen to extend that date, so it should be taken into account when considering appropriate time span.

Another thing that needs some attention is the blockchain structure. This means you can not just drop some of the blocks in the chain, you would have to remove all of the blocks from the genesis block to the certain point and after that the next block should become the new genesis block. This process would also have to utilize consensus to keep the system in check.

This system should also be very simple and easy to use for the users, especially the customers, despite being more robust on the back-end side. The backbone of the system should be easily expandable in the future since supply chains can change constantly and new needs are found out over time. QR codes for opening specific websites would be probably the best option since it is very accessible. Ultimately this system would offer more transparency for the food that consumers buy and this would be big boost for the safety of food products.

One common platform that anyone could join and use would be most ideal but this has so many different challenges that I think it would not be ready for use in the next decade, but at some point I could see this becoming a thing. Depending on the data collection coverage in the supply chain, different trust levels could be assigned to the members. This way special devices are not required but promoted. This common platform could be open source for trust reasons and further development. The good thing with this is that companies can use multiple chains alongside each other.

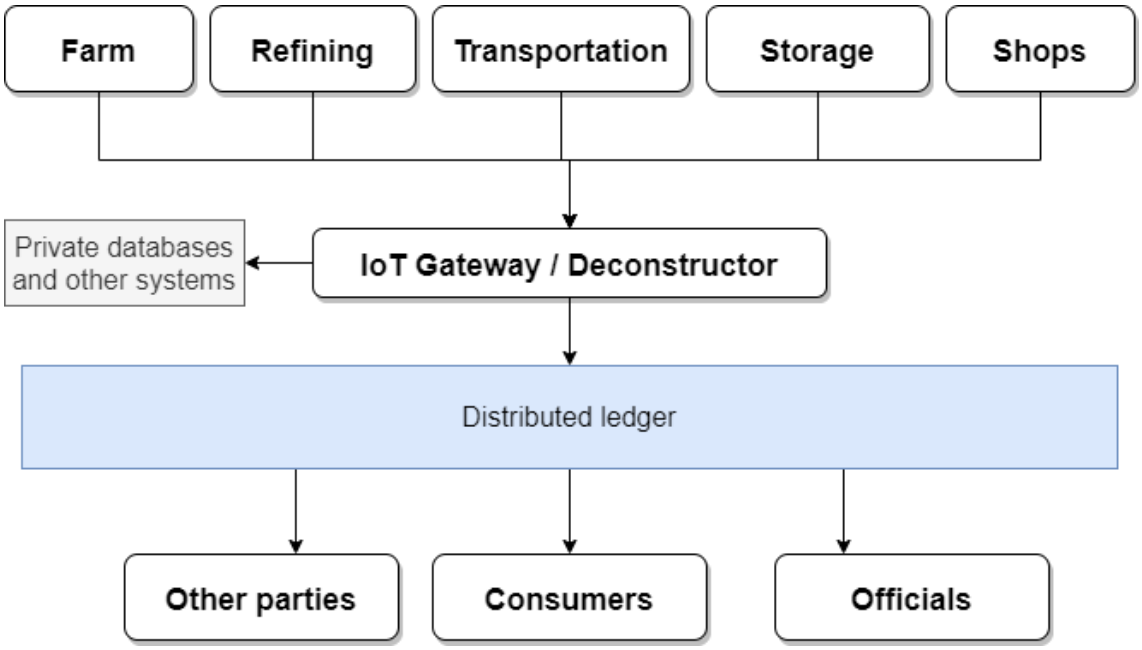

Figure 5.1: Data flow

There are several business needs for food supply networks that should incentivize various sizes of companies to start looking into these systems to innovate the market. Business goals are very common reasons to adopt new technology and implement other changes. For supply chains improving it over time is the common goal for all. This process needs unbiased data to identify problematic areas and the trusted food tracking would also provide that.

The flow of data in a trusted food network is shown in Figure 5.1. This approach would allow running the distributed ledger and other current private systems side by side before the possible full transition to the distributed ledger based system. This transition does not have to happen instantly. However, that should be the goal down the line. Each stakeholder in the supply chain would ideally have their own full local node that participates in the ledger functions.

The data flow starts at the various stakeholders where various IoT devices gather data and send it to the gateway. Some other data sources could be included but IoT

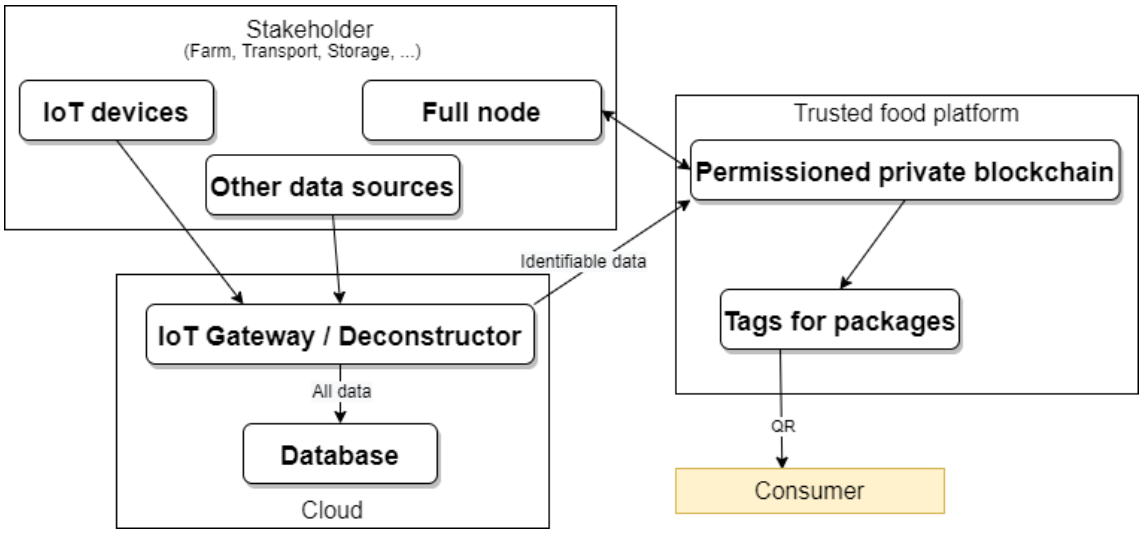

Figure 5.2: System architecture

is preferred due to the automation and low maintenance. The IoT Gateway is hosted in the cloud to avoid data loss and other issues. The maintenance of gateways at each stakeholder could become very cumbersome so avoiding that is preferred.

The platform of choice for the blockchain is important for the desired features but most of the distributed ledger platforms are suitable for business applications. Hyperledger Fabric could be chosen for this since it supports permissions and smart contracts which are essential for a business network. The permissions in the private distributed ledgers can be used to limit access to the data despite all major stakeholders having their own local full nodes as seen in the Figure 5.2 and these nodes form a peer-to-peer network. The owner of the data has always access to their own data and it can be accessed and used for various things just like with database based systems. The other parties can access data from others depending on the set permissions.

This one common platform approach would allow better data sharing and collaboration with others in the supply chain. Some general information could be made available to the government officials if desired. Even this can be limited with the

permissions. The consumers should only be able to read the information stored for the specific product that they scan with their phone. This is possible by giving the physical item a digital identity to link the gathered information to.

This open approach would solve the lack of transparency in the food supply chain and it could be used to promote optional collaboration with the stakeholders. This added service creates more value for the included products and it should have a positive impact on consumers that have dealt with general loss of trust to food products due to the several different food scandals around the world. This has lots of potential for improving the trust and sales of exported food for example. It could also be used to create more premium products that are constantly monitored to ensure the best possible quality.

Several research reviews about the application of blockchain technology in food supply have already been released so far. This one is more extensive since this also covers the effects on the upcoming food technology which could use distributed ledgers as the storage platform of choice. Before this though there are potential issues with DLT and IoT that need solving and some of the possible solutions from the other publications were mentioned earlier. Also, there was more effort put into highlighting that a system like this should also focus on several things to improve. There is a lot of room for logistics, collaboration, transparency and more in a complete tracking system.

Large supply chains can be very complex and because of this improving them is a big challenge. By increasing the information gathering, the decision-making process can improve. Regardless of the type of the supply chain, these are very essential services for everyone and identifying problematic spots can make a big difference. There are also several other factors that cause supply chains to fail. These issues are not easy to fix but fixing common pitfalls over time should make a big difference later.

6 Conclusion

Distributed ledgers have a lot of potential to change the current food supply chains into more open and secure systems. Ultimately this could be considered the next generation of supply chains that collaborate more often than currently. The potential benefits for these systems are alluring and based on those the adoption of blockchain technology should pick up in the future unless something better ends up replacing blockchain.

The high amount of wasted food around the world should be a big concern everywhere and anything that can alleviate that issue should be pretty high on the priority list. Other big issues are food forgeries and contamination which are an issue around the world to a varying extent. These both require detailed tracking to solve properly. DLT based systems can contribute into fixing these issues with food products.

This innovation does not really stop at supply chains either. There are countless different application areas outside of the food sector for blockchain technology. It could be very beneficial for the crowd sourced platforms where some of the users might participate in the upkeep of the whole system. File hosting and personal storage are a great example where users can store files in a system for personal storage or sharing. Distributing the storage could be a very good option and paying for people who host it and allocate storage could be very beneficial.

Depending on the implementation this could be more secure and privacy oriented

than the currently available centralized options. There are already platforms like this and this trend seems pretty good. This idea could even be expanded to computation side of things later similarly to folding@home[1] where anyone can spin up a machine for computing tasks. At least computing different real tasks would be more useful than the mining process with certain consensus methods with arbitrary tasks.

Some other possible uses for blockchain were briefly mentioned. There are countless other possible use cases including healthcare, banking, smart homes, smart cities, automotive and insurance. These could gain benefits from a trusted distributed storage and smart contracts. These trusted systems could also cover electronic voting systems by government entities in the future and this could help avoiding foreign criminals from meddling with official votes even though the voting could be done remotely. The potential applications seem endless since there is a lot of potential to utilize the trusted storage in several fields and locations.

Blockchain is not flawless either just like the other data storage options and there are issues that need to be researched further and solved. While there are many consensus options available, most of them have not been tested in actual applications and in large scale. The potential performance issues are currently very restrictive and these straight up rule out some time critical applications.

Overall, distributed ledgers are very interesting data storage option and perhaps over time they will become the norm for supply chains and product authenticity verification. The current state of the food supply chains is not very good since occasionally problems pop up which may have severe consequences. Food safety needs innovation and solutions around the globe. Being more open with the data does bring some benefits and it should get more common. Though various business secrets and very firm culture of keeping everything private are both big blockers for this goal.

[1] `https://foldingathome.org/`

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