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Master of Informatics

Master's Thesis

Organic food Traceability and Technology

How can Information Technology (IT)
improve food traceability in the organic
Food Supply Chain (FSC) in Europe?

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Abstract

Consumers who buy organic food, have expectations about its quality and rely on certifying organizations to verify this quality and to provide information about the origin of organic products. However, organic food traceability knows several issues, such as problems with organic labelling, certification fraud and transparency issues. Although current technologies and data exchange formats already allow for information sharing between chain partners, it is unclear which companies or projects in the organic food industry are successfully using Information Technology (IT) solutions to improve organic food traceability from ‘Farm to Fork’. The main research question is therefore: “How can Information Technology (IT) improve food traceability in the organic Food Supply Chain (FSC) in Europe?”.

This thesis presents a study, which aimed to evaluate several cases in light of the European Union regulations around food traceability. Considered from a theoretical and system perspective, the combination of sensing, detecting and software technology has found to be able to contribute to organic food traceability.

The empirical results of the case study showed that implementing Blockchain technology could provide benefit because of its characteristics of immutability, distributed ledger technology and the ability to exchange data amongst chain partners. It was recognised that traceability projects could be technology driven and identify issues in the supply chain around traceability as well as improve relationships between chain partners. Case study found that regulations and standards are seen as a wholesaler or retailer responsibility. Increased accountability for the Food Supply Chain (FSC) towards its consumers was found as well.

The key explanation of how Blockchain, as the most qualifying technology, can improve food traceability in the of organic FSC is the combination of ‘chain discovery’ and ‘data capture’ and making the relevant choices depending on the characteristics of the organic chain.

Whether or not driven by technology, warnings from a Non-Governmental Organisation (NGO), a food incident or the ambition to increase consumer satisfaction, improving whole chain traceability can be done without Blockchain technology. Nevertheless, it could be a good solution for a complex FSC.

Considerations for using Blockchain technology are discussed along with several fruitful areas for further research directions.

Preface

During the writing of this thesis and the work that led up to the moment of completion, I have had the opportunity to reach out to several people with whom interesting conversations about food traceability and technology took place.

Complex food chains and the quality of food interrelate in many ways impacting consumer and planet health. Although this research was triggered by concerns about this topic, I have gained many additional insights on how to improve food traceability positively impacting the two most important sides of the organic food supply chain, the farmer and the consumer.

Professionals working in the food supply chain on Blockchain projects, who contributed to this research and worked with me on it during interviews, showed great enthusiasm, for which I thank them. It was a true delight to notice how, even when time seemed limited to them, they agreed to provide valuable information without anything in return.

The time invested in taking master classes away from home and studying at my home office did not go unnoticed. I thank my partner, children, family and friends for their endless, loving support.

Thanks goes out to my colleagues at the Utrecht University of Applied Sciences at the Business IT & Management program for their compassion during the entire two year program.

Despite his busy schedule Guido Ongena provided guidance and support which greatly benefitted both the research and the writing of this thesis. Thank you Guido!

Thank you to my fellow students Erwin Koens, Judith Kats and Sanne Staat for sharing their experiences during the program and all the laughs.

For the quality review of the English writing of this document, I thank Paul Satterly. It was a good reason to get back in touch and discuss the emerging Blockchain technology and other interesting, somewhat related topics, such as gardening.

June 4th 2019, Mireille van Hilten

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1. Introduction

"Since the environmental concerns in the food supply chain grow, to design and implement an eco-friendly supply chain will be a new challenge"

(Aung & Chang, 2014)

Sustainability is an important theme in the food supply chain (Lehtinen, 2017; Papetti, Marconi, Rossi, & Germani, 2019) and customers demand information about a product's impact on the environment (Lehtinen, 2017; Schleenbecker & Hamm, 2013). Examples of the movement towards a sustainable world are carbon footprint awareness, waste and pollution reduction, fair working conditions and the use of quality raw materials, such as food that has been grown organically.

Organic food is booming business at the moment. According to a European Commission report, the organic sector in the European Union (EU) has seen rapid development during the past years. Where the EU had 5.0 million hectares of organic agricultural coverage in 2002, in 2015 a total area of 11.1 million hectares was organically cultivated (European Union, 2013). More and more organic alternatives for processed food products appear in supermarkets. Some consumers are willing to pay more money for organic food than for non-organic food. They rely on the trustworthiness of food labels and certificates. However, is this information trustworthy? Alternatively, is this food actually organic?

Companies in the organic Food Supply Chain (FSC) may set strategic goals like increased sales of organic products to meet consumer needs and increase their organic food market share at a fair cost. At the same time, they need to align that strategy with external influences, such as environmental issues, regulations and standards, the public opinion and increased consumer demand. How can companies keep up with the growing demand and at the same time ensure food quality?

In the 1970's organic food certification organizations were established to control food quality. Supposedly there are now over 250 organic labels in Europe (Big Room Inc., 2019). Does an organic label mean that the product is completely free of toxic pesticides? Does the label even have the right information on it? 'Farm to Fork' transparency laws and standards attempt to regulate the use and exchange of information between companies in the chain; the FSC partners.

Enterprise Resource Planning (ERP) systems to optimize planning of operational processes, sensoring technology (for example Radio Frequency Identification) for product tracking and interoperability between systems are examples of current technologies in the FSC. These Information Technology solutions for Supply Chain Management (SCM) may or may not positively impact transparency of information about organic food. Implementing technologies in the FSC to improve traceability comes with issues, like cost, adoption and many more, impacting what is called 'whole chain traceability' of food.

Referred to as ‘emerging’, other technologies to improve SCM and food traceability are used in the FSC as well. The Internet of Things (IoT), which can be seen as a sensor network, is used for tracking products through supply chain (Dujak & Sajter, 2019). Analytical tools, also referred to as Data Analytics, Big Data and the usage of algorithms combine large amounts information in real-time which help organisations to discover new opportunities, products and services (Ji & Tan, 2017). Blockchain is an emerging technology having the capabilities of guaranteed data immutability and public accessibility of information (Dujak & Sajter, 2019). “Blockchain can increase the efficiency, reliability, and transparency of the overall supply chain, and optimize the inbound processes supports trust and transparency” (Perboli, Musso, & Rosano, 2018).

Initially, the disadvantage of Blockchain technology was the rare application to the FSC, but more and more initiatives are found in the FSC at the moment. The Danish company Maersk, for example, is running a Blockchain solution which started as a prototype in the beginning of 2018. The ecosystem that is running on this global trade solution is made up out of more than 90 organizations.

Food and also other supply chains are becoming increasingly complex, in which many companies interact with each other and the consumer and in which products transform as they pass through the chain, as illustrated by *Figure 1* ‘The Food System’.

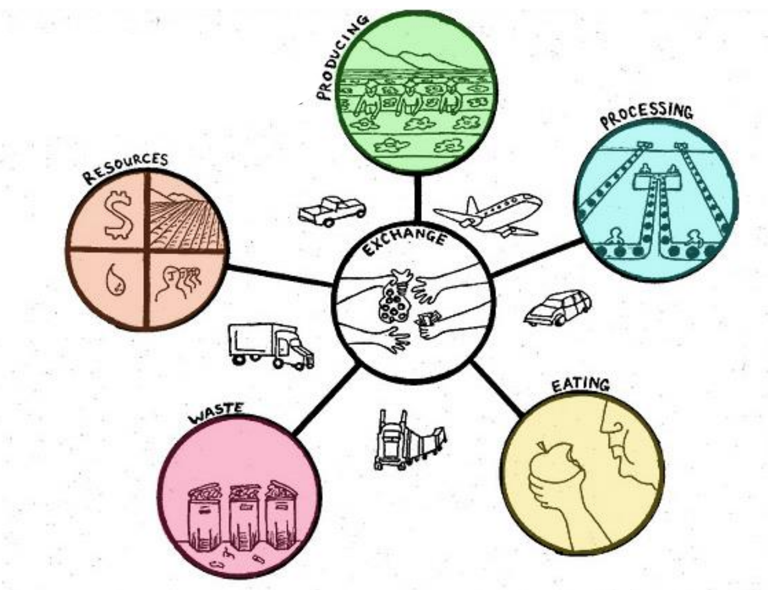

Figure 1: The Food System (Wikimedia Commons)

Though answers to the questions above are more likely to be found during the course of time as the FSC continues its digital transformation (also referred to as 'Industry 4.0'), this research does attempt to at least identify the food traceability projects that have an actual impact on the transparency of food information and the traceability of organic food. The role that Information Technology and the emerging Blockchain technology plays in these projects is evaluated to understand if this is the case. The focus on the organic FSC has been chosen, because of personal concerns about the quality of organically certified food in the FSC. Academically, the outcomes of this research will show which technologies improve the traceability of organic food.

1.1. Problem statement

The international Food Supply Chain (FSC) is under pressure to provide information about environmental impact, food fraud, quality and safety (Langelaan & Silva, 2013). Several food crises occurring over the last decades have increased consumer demand for high quality food and easy access to food information (Schleenbecker & Hamm, 2013). Secondly, food travels increasingly large distances from producer to consumer ('Farm to Fork') because of globalization in the food eco system (Lehtinen, 2017).

The use of pesticides concerns the entire food chain, not just the organic food chain. Using pesticides in farming has led to health issues and even death in for example Africa and constitutes of the third largest health cost in the continent (WECF, 2012). If it turns out an organic product is not actually organic, the consequences for Supply Chain participants could be severe. One example in The Netherlands led to a mushroom scandal for the supermarket chain Albert Heijn, which in its turn led to the liquidation of the local mushroom grower after retraction of the organic certificate by Skal (Trouw, 2008). The European Food Safety Authority (EFSA) has also identified issues around pesticides in organic food (EFSA, 2009).

Since 2012, EU FSC participants must include information about the manufacturer, seller, importer, storage conditions and preparation of certain foods on food labels. Controls deducted by the EFSA were instated at the time this General Food Law was publicized (European Union, 2014). Compliance and other drivers (safety, quality, competitive advantage, trade globalization, chain communication, labor/cost reduction and process efficiency) for transparency create a need for Information Technology systems solving current issues (Aung & Chang, 2014). Traceability issues in the chain are; the complexity of the FSC, increased amounts of data, high cost, interoperability, trace back issues, lack of standardization, confidentiality concerns, transparency and farmer adoption.

Currently, several pilot projects aiming to improve FSC traceability are in flight. In the Netherlands alone, 4 pilots were identified in the early stages of this research (Tony Chocolony, AH, Fish Tales, Verstegen), some of which focus more on sustainability and fair-trade food, not organic.

It is unclear which companies or projects in the organic food industry are successfully using Information Technology solutions to improve organic food traceability. Not to mention it is not clear what these solutions are. The origin of food is especially important in the organic FSC, because it can indicate the use of pesticides, (Genetically Modified Organisms) GMO's and how sustainable the production of the product was. Detection technology solutions are being developed to be able to automatically indicate pesticide use in food. Which ones can or are used in the FSC is unclear. The type of food may even determine the sensing technology necessary in these cases.

Currently, Blockchain technology draws much attention as a possible disruptor in various industries. The aim of this research is broader than one technology and thus a broad range of technological solutions are analysed such as following FSC/traceability standards and open standards using XML (Mainetti, Patrono, Stefanizzi, & Vergallo, 2013; Zhang, Huang, Zhu, & Qiu, 2013). However, it is pivotal to stipulate that specific attention is paid to Blockchain technology as a possible solution to the above problem statement, mainly because Blockchain supports trust and transparency.

1.2. Research question

The objective of this research is to evaluate the use of Information Technology in the FSC, specifically for the organic food chain in light of the regulations around food traceability. The fair-trade food chain can be used as a comparative industry, because it also involves certifying organizations. Europe has been chosen as the field of research, due to the fact that regulations are organised at the level of the European Union.

The research function is to evaluate several cases in light of the regulations around food traceability. To keep the research scope manageable, the focus is set on *fresh* or *green* crop (produce) within organic agriculture, not on organic meat produce or organic food processing.

Another point of focus is *backward traceability*, because the research investigates traceability of the origin of food, focusing on the absence of pesticides or other pathogens. Forward traceability means food products can be pulled back from stores in case of an issue with the quality of the food. This is out of scope for this research. The main research question is:

How can Information Technology (IT) improve food traceability in the organic Food Supply Chain (FSC) in Europe?

Table 1 on the next page shows the sub research questions in need of an answer to be able to provide a comprehensive, validated answer to the main research question. Please refer to *Table 4: Research method per sub question* on page *27* for detailed information about methods and techniques and per sub question.

	Sub research questions	Research function	Insight
1	Which core business processes enable food traceability in the organic Food Supply Chain (FSC)?	Describe	Knowledge about the FSC and traceability processes as a foundation for the research.
2	What is the effect of European legal regulations and standards on food traceability in Europe?	Describe	Discernment of food traceability phenomenon in relation to the most recent regulations.
3	What are current traceability issues in the organic FSC in Europe?	Describe	Summary of traceability issues to identify factors influencing organic traceability.
4	How do current technologies affect food traceability in the organic FSC?	Evaluate	Overview of current technologies used in organic FSC, understanding of factors influencing organic traceability.
5	How can Blockchain improve food traceability in the organic FSC and what are considerations in current projects?	Evaluate	Analysis of projects with actual impact on traceability of organic food.

Table 1: Sub research questions

The last question focuses specifically on the Blockchain technology. The rationale for this is that none of the current Blockchain projects in research have investigated how Blockchain can contribute to the traceability of organic food. And though Blockchain and other technologies seem successfully implemented in a few cases (Kshetri, 2018; Mainetti et al., 2013), in other studies in the literature found, cases were described from a technical design point of view, from a model (Casado-Vara, Prieto, La Prieta, & Corchado, 2018; Ji & Tan, 2017; Zhang, Huang, Zhu, & Qiu, 2013) or within a pilot or testing scenario (Bhatt & Zhang, 2013). One study stated that case studies researched so far lacked technological information to prove their success (Galvez, Mejuto, & Simal-Gandara, 2018). The evaluation of whether or not a Blockchain project is a successful implementation in the FSC to improve organic food traceability, has yet remained unclear.

1.3. Scientific and practical contribution

Many articles about Information Technology in the FSC describe process optimization and a significant amount of papers also describe FSC traceability. Research aiming to improve transparency, investigating information, detection and sensing technology specifically for the organic FSC can be considered state-of-the-art research. Through investigating current issues in the organic FSC and how technology improves food traceability, the rapid development of the organic food market can continue.

Blockchain technology has scarcely been researched in connection with supply chain traceability (Galvez et al., 2018). All of these statements underpin the importance of research in this relatively unexplored field. In the preliminary literature review, Galvez et al. stated that no detailed information about the technical implementation of Blockchain technology in pilot projects has been reported (2018). In this paper it was also stated that Blockchain technology should be properly evaluated, proposed solutions should be evaluated against alternative solutions and that a universal evaluation model does not yet exist (Galvez et al., 2018).

Research on the application of big data in other areas of the FSC than production need further research (Ji & Tan, 2017). Aung & Chang (2014) claim that most research focused on traceability until the retail point of the FSC, not tracing all the way through to end of the chain; the consumer. How Blockchain lead to benefits compared to existing IT solutions needs careful attention by further exploring use cases in order to get the conservative logistics industry more excited about Blockchain (Hackius & Petersen, 2017).

The first and most important contribution of this research for practitioners is what it can mean for actors in the FSC, including farmers. Many business needs and management objectives were found in the literature, ranging from better product quality, increased production performance, effective and/or faster recall of food, more trust between chain partners to regulations and standard compliance. To FSC partners this research provides documented use cases to be considered as best practices and a current overview of technologies used. Concise information about food traceability technology will accommodate management decisions concerning the digital transformation of business processes.

Secondly, the consumer is an important stakeholder as well. There is a variety of consumer benefits from increased transparency, better food quality to providing feedback to farmers. This research will propose guidelines to improve FSC traceability using technology. In turn this potentially increases consumer confidence.

Finally, the role of certifying organizations may change over time if Blockchain and/or other technologies are increasingly adopted in the organic FSC. Because Blockchain creates trust between companies, the trust that the FSC and the consumer put in certifying organizations may be impacted. To them the research provides a current overview of technologies used and a viewpoint on why companies would consider using Blockchain technology.

2. Literature review

A review of relevant literature has been conducted which provides the theoretical underpinnings for this study. The research method is described in detail in paragraph 3.1. Over 70 peer reviewed scientific articles were found in the literature, covering the FSC, supply chain management, food traceability and technology were identified. Concerning sustainability related topics, 24 articles were found of which a focus was either on the organic food chain or on traceability in relation to a sustainable food chain. Only a handful of articles address food traceability specifically concerning the organic FSC.

To define the main concepts around the organic supply chain in paragraph 2.1, the starting point is the term ‘organic’. Definitions of ‘organic’ are provided in first, including the main stakeholders involved (2.1.2). Definitions of the FSC (2.1.3) and food quality (2.1.4) lead up to the explanation of the process of certifying organic products (2.1.5) to assist the identification of traceability improvements the organic FSC later on in the chapter Results.

The term ‘traceability’ related to the FSC has many references in literature, as discussed in paragraph 2.2. Which types of traceability are known (2.2.1) and current issues in the food chain that have to do with the traceability of products (2.2.2) will allow for a solid evaluation of current and emerging technologies further along the research. The third paragraph pays attention to the technological aspects of food traceability. The basis is a definition of a food traceability system (2.3.1). To be able to consider if technology could play a role in detecting pesticides of organic food, sensing and detecting technology is described at a high level (2.3.2). Whole chain traceability of product information and products themselves by using Blockchain technology have been subject to research in the last few years, which is highlighted as well in 2.3.4. The final part of the theory review (2.3.5) describes the adoption of information technology, and specifically adoption in the supply chain and FSC.

2.1. Organic food

Due to the fact that the term ‘organic’ is often used with different meaning and to crystallise the term, this paragraph starts with a definition. To clearly identify the most important roles in the supply chain, the main stakeholders are described next (2.1.2), followed by general information about the FSC (2.1.3). To be able to zoom in on the way technology is used for food traceability, aspects of food quality are described in 2.1.4. Because organic food quality is often verified by certifying organizations, sub paragraph 2.1.5 reviews the certification process in Europe.

2.1.1. Organic defined

To research traceability in the organic FSC, understanding of the term ‘organic’ needs to be established. The International Foundation for Organic Agriculture (iFOAM) addresses the health of soils, ecosystems and people and provides as a holistic view of organic farming, including the use of inputs that do not have adverse effects and has fair relationships. Browne, Harris, Hofny-Collins, Pasiecznik and Wallace (2000) describe ethical trading and organic production as two separate concepts and discuss how far these two concepts should be linked. The first concept is branched into a people, an environment and an animal focus to ethical trade. The people-centred focus is also known as fair-trade, which can take into account the working conditions of for example farmers, including fair payment. Verhoog, Lammerts Van Bueren, Matze and Baars (2007) use the term naturalness at three levels to describe the word ‘organic’ in relation to agriculture. The first level describes the usage of substances from natural origin instead of synthetics. Sustainability together with agro-ecology and protecting living organisms make up the other two manifestations. Browne et al. (2000) state that organic production does not need to represent the full list of ethical considerations. Verhoog et al. (2007) call this the no-chemical approach that does not permit materials or techniques like synthetic pesticides, inorganic fertilizers and GMOs, often leading to the conversion process from conventional to organic farming. Verhoog et al. view this approach as a rather limited view, because non-chemical pesticides are believed to be not just better for the environment, but also healthier for humans. For the purpose of this research, the definitions of organic are all considered relevant, yet the research focus is specifically placed on the no-chemical approach as described by Verhoog et al. and the organic production concept found by Browne et al.

2.1.2. Stakeholders

The primary stakeholder for the FSC to provide organic food is the European consumer. The consumer is the actor in the food process that buys the products and considers them of value. According to a Vision Paper based on discussions between farmers’ organizations, scientists, organic traders and retailers, and EU organizations, an increasing number of organic food consumers expect more from organic products than from conventional products, to support the considerably elevated prices (Ifoam & Isofar, 2008).

Other stakeholders are also impacting sustainable practices, like the government being a very important stakeholder in environmental matters, environmental organisations, which nowadays are involved in approving sustainable working practices, financial institutions, as well as academic research and supply chain actors. Since many large FSC’s act globally, world-wide involvement, requirements, and consequences have to be taken into account (Wognum, Bremmers, Trienekens, Van Der Vorst, & Bloemhof, 2011).

2.1.3.The food supply chain

The Food Supply Chain (FSC) is defined by the ISO 22000 standard as “a series of consecutive steps and operations with regard to production, processing, distribution, storage and handling of food and ingredients, from primary production to consumption” (ISO 22005:2007, 2007). The European FSC can be considered ‘European’, because countries import food from all over the globe into Europe and food is produced in Europe as well. In the supply chain, chain partners as depicted by Roth, Tsay, Pullman & Gray (2013) in *Figure 2* all play an important role. A FSC becomes more complex when the final food product is one of many ingredients. The distance that food travels along the supply chain from the farm where it is harvested to the consumer, is now longer than ever before (Aung & Chang, 2014), due to globalization and an increase international trade.

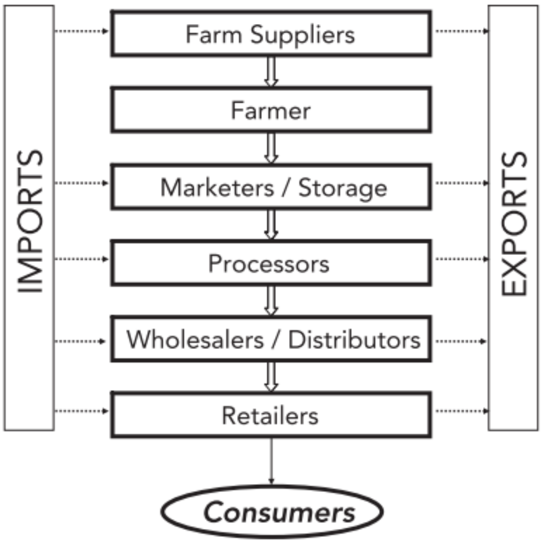

Figure 2: Generic model of Food Supply Chain - one ingredient (Roth et al., 2013)

Kottila, Maijala and Rönni found shortcomings of the information flow by the chain partners and the information delivery to the consumers, which impacted the performance of the organic food chain. Actors from outside the chain could support the organic chain by managing and providing information concerning the ethical, ecological and societal value of organic food (Kottila, Maijala, & Rönni, 2005).

Recently, sustainability of the food chain related to climate change is on the agenda of many companies and governments and promoted by the United Nations Sustainability Development Goals (SDG’s) (United Nations Sustainable Development, 2018). In the supply chain that could lead to, for example, the measurement of the carbon footprint of one single product throughout its journey through the chain. Sustainability of the supply chain itself, however, is not part of the scope of this research.

2.1.4.Organic food quality

Organic food quality is seen in many different ways. Food quality can be defined by distinguishing process- and product- related aspects. They are described and evaluated by using criteria, indicators and parameters. There are many factors influencing the quality of the food as moves through the supply chain process (Kahl et al., 2012). Looking at the quality of food from a broader perspective, it is strongly related to consumer expectations and promises. From both perspectives it is important for chain partners to measure and manage food quality. When regarding organic food quality from the perspective of regulations this is a another definition: "Organic products derive their high quality from compliance with strict health, environmental and animal welfare standards in the manufacture of these products" (Council of European Union, 2018).

During a study on the definition of organic food quality, a framework of concepts was developed and food quality was evaluated by looking at the European perspective and current EU regulations (Kahl et al., 2012). It was stated that understanding three organic criteria, coming from these regulations, by all actors in the food chain is more important than rating them. The study provided more detailed definitions of these criteria as listed in *Table 2*.

Vital qualities, organic integrity and true nature	Organic integrity	True nature
Indicate how 'self-organization' of an organism is expressed as 'resilience' (elasticity, capacity to cope with challenges). This may be related to the product itself or to the effect of the product on the consumer (capacity to reconstitute after a challenge).	Organic integrity comprises the inner structure, coherence and order of the product (as indicators). Integrity can also be defined as a process-related quality criterion. Here integrity is being described as part of the influence of the production process on environment, animal welfare, social responsibility, etc.	True nature represents species-typical characteristics of the unprocessed food. The true nature of the processed food should – without reconstitution – maintain the typical characteristics of the raw material. In order to maintain the true nature of the pro- cessed food, specific characteristics of the raw material could be included.

Table 2: Organic criteria defined (Kahl et al., 2012)

It was concluded that organic food quality needs to be developed further and that concepts, definitions and evaluation methods could change during its development (Kahl et al., 2012).

2.1.5.Organic food certification

Organic food certification is based on European regulations (see also *Traceability regulations 2.3.6*) that formally assign inspection organizations for each European country (European Commission, 2018). Ecocert is a well-known organization, certifying for example the French and German organic food market.

In The Netherlands, Skal certifies organic food which can be home grown as well as imported. With EU legislation 396/2005 on the usage of pesticides, the European Committee has established maximum residue limits (MRL) of pesticides permitted in products of animal or vegetable origin that are intended for human consumption, including a list of forbidden pesticides (European Commission, 2005).

Figure 3: Examples of organic certification labels globally (Koekoek, Leijdens, & Rieks, 2010)

In light of the research topic concerning traceability of the usage of pesticides, it's worth noting that farmers go through a period of conversion to obtain an organic certificate. The certifying body will monitor the farm in the first year, at which time the products are not certified as organic yet and will also not yet be sold for a premium price. While conversion can usually be achieved in one year for export to the EU, in places where agrochemicals could be used, the period to convert to organic farming will be three years (CTA & Epopa, 2006).

Certification is a time-consuming procedure for a farmer. Building trust with the certifying organization and creating a solid working relationship makes inspection easier (Koekoek et al., 2010). The certification process is aimed at verifying various aspects of organic farming and farms are inspected once a year (European Commission, n.d.). Each certifying body could be at a different level of advancement in terms of implementing traceability (United Nations Global Compact Office, 2017).

Despite the fact that regulations were followed by the certifying body Skal (Skal, n.d.), doubts were raised among consumers in May 2019 after analysing organic certifications in The Netherlands (NOS, n.d.). The plethora of organic labels and other certifications make is difficult for a consumer to be able to trace a product back to its origin (Lehtinen, 2017). A study in the year 2000 showed there is potential for organic food to also be certified as fair-trade, by following a holistic definition. This can be done by adding additional social criteria to the standards used by the certifying bodies, based on the organic regulatory authorities (Browne et al., 2000).

2.2. Food traceability

Food traceability is defined by Olsen & Borit (2013) in a designated article on defining traceability: "The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen & Borit, 2013). Aung and Chang consider several other definitions, some from ISO standards, followed by Olsen & Borit and then adhere to "Food traceability is defined as a part of logistics management that capture, store, and transmit adequate information about a food, feed, food-producing animal or substance at all stages in the FSC so that the product can be checked for safety and quality control, traced upward, and tracked downward at any time*"* (Bosona & Gebresenbet, 2013). Bi-directional traceability is added to the definition, meaning to be able to trace back and trace forward. Trace back means a contaminated product is tracked to its origin and leads to source identification. Trace forward means that retail or consumer products can be identified and called back.

2.2.1.Traceability types

According to Opara (2003) six elements of traceability together are needed for an integrated system for agricultural FSC traceability system. Two of those are applicable to organic food quality when the usage of pesticides is concerned; genetic traceability and inputs traceability.

Genetic traceability	Inputs traceability
Determines genetic constitution of the product, including type and origin (source, supplier) of genetically modified organisms/materials or ingredients, planting materials (seeds, stem cuttings) used to create the raw product	Determines type and origin (source, supplier) of inputs such as fertilizer, chemical sprays, irrigation water and the presence of additives and chemicals.

Table 3: Organic traceability types (Opera, 2013)

The other aspects are traceability of *product*, *process*, *diseases and pests* and *measurement*. The latter represents traceability of test equipment and quality of measurement data. Although product and process traceability do not specifically concern organic food traceability, they are imperative for all food types, including organic food.

A more recent study breaks process traceability down even further into the identification of the premises, representing the actual location of a product, and movement tracking, which indicates the time and location of product movement (Bhatt, Buckley, McEntire, Lothian, Sterling, Hickey, 2013). Product traceability is considered to be product identification throughout the chain and does not consider how information about the origin, such as organic certifications, can be traced.

Food traceability splits up into internal traceability and external traceability, according to Moe (1998). Internal tracing constitutes the tracing food products in one of the steps in the food chain, meaning one chain partner, for example the producer where products are prepared and packaged. Internal tracing is when all inputs are matched to outputs (Charlebois, Sterling, Haratifar, & Naing, 2014). External traceability or chain traceability tracks a batch of products and its provenance through the entire chain or a part of a food chain, from the origin when the products are harvested through transport, storage, processing, distribution and retail (Moe, 1998). This external traceability is of most concern for the consumer, because it discloses information about the origin of (organic) food. Even earlier than Moe's research from 1998, the distinction between vertical and horizontal traceability was introduced from a software development viewpoint by Lindvall & Sandahl in in 1996. It was stipulated that it's possible to trace items within one model that are dependent (vertically) and to trace correspondent items between distinct models (horizontally), thus differentiating vertical and horizontal traceability.

Bhatt et al. (2013) state that one-up/one-down traceability or internal traceability is often interpreted by individual companies as "already having traceability". To build whole chain traceability internal traceability is undoubtedly a prerequisite, however not sufficient.

Each chain partner must be able to share product information with surrounding partners in the chain, yet also maintain system connections for tracing purposes to guaranty fast and trustworthy flow of traceability information (Bhatt et al., 2013). In 2014, Aung and Chang also used the term 'whole chain traceability' (Aung & Chang, 2014) while they refer to the importance of 'Farm to Fork' traceability in the overall food quality assurance system (Opara, 2003). Challenges around full traceability are especially critical for food chains involving multiple tiers of suppliers or various sources (United Nations Global Compact Office, 2017).

2.2.2. Traceability issues

The FSC is considered to be extremely complex and needs to deal with several different issues impacting traceability along all stages of the chain: production, processing/packaging, distribution, retailing, consumption and disposal (Zhang et al., 2013).

Eight drivers for traceability were identified by Aung and Chang (2014), such as legislation, competitive advantages, chain communications and supply chain efficiency. Another driver found in the alimentary food chain are security risks (Casado-Vara et al., 2018).

Figure 4 highlights at least nine issues types found in the literature. Complexity in the food chain was an issue described in many articles (Aung & Chang, 2014; Casado-Vara et al., 2018; Galvez et al., 2018; Olsen & Borit, 2018; Zhang et al., 2013).

Interoperability focuses on the sharing of data between systems in relation to the use of standards (Bhatt & Zhang, 2013). A generic data model for traceability is proposed by (Bechini, Cimino, Marcelloni, & Tomasi, 2008) to be able to integrate data along the supply chain, which however is joined by a time consuming process to realize traceability ontologies within a specific domain.

The issue of enormous amounts of data, sometimes coming from larger amounts of (detecting) devices is one issue that is directly addressed by proposed emerging technologies, such as Big Data, Internet of Things (IoT), Multi Agent Systems (MAS) and Blockchain technology (Hackius & Petersen, 2017; Ji & Tan, 2017; Zhang et al., 2013). Considered from a process and technology perspective and not from a business driver perspective, cost of processing and technology is the next type of issue described. For example the high cost of RFID tags found in 2013, yet passive RFID tags require no battery and are becoming very cheap (Olsen & Borit, 2018).

Complexity
Amount of data
Costs
Interoperability
Lack of records
Product traceback
Standardization
Granularity (TRU level)
Transparency

Figure 4: Traceability issue types

Massive (manual) record keeping, lack of records and inefficient approval collection are leading to errors and additional cost in the FSC process (Galvez et al., 2018; Hackius & Petersen, 2017; Kshetri, 2018; Mainetti et al., 2013; Olsen & Borit, 2018). Bollen, Riden, & Cox (2007) state that the precision of traceability can be quite different between successive outputs, which is called granularity. The adoption of granularity levels is identified as an issue in a summary of traceability pain points by Dasaklis, Casino, & Patsakis (2017) due to process complexity.

Transparency was seen as an issue, meaning that all stakeholders participating in the chain, including the consumer should have access to food information (Aung & Chang, 2014; Casado-Vara et al., 2018; Galvez et al., 2018).

2.3. Traceability and technology

To be able to deal with the complexity of food chain traceability, many scientific studies aimed to develop frameworks and models of traceability systems. To achieve food traceability in the supply chain, information systems are used to record and track food information. The definition of a traceability system as documented by the International Standard Organization is the “totality of data and operations that is capable of maintaining desired information about a product and its components through all or part of its production and utilization chain” (ISO 22005:2007, 2007).

Earlier definitions define a traceability system for example as a "record keeping system" (Golan et al., 2003) and ten years later Olsen and Borit (2013) discuss two hypothetical traceability systems. Online location tracking of food with all ingredients, monitoring and permanent recording of the position data constitute the first system. The second one is represented as a fast instrument for accurate analysis using all methods and instruments available to verify properties of a food sample. Both visionary systems provided their research with the necessary components of a traceability system, which at the time led to their conclusion that a solid academic traceability definition did not exist.

2.3.1.Traceability system

Moe (1998) pictured the fundamental structure of a traceability system in an article. A set of core entities already provided by (H. Kim, Fox, & Gruninger, 1995) was extended with descriptors essential to secure ideal traceability of products and activities (core entities, *Figure 5*). By selecting the number and content of sub-descriptors the scope of a traceability system is put in place (Moe, 1998).

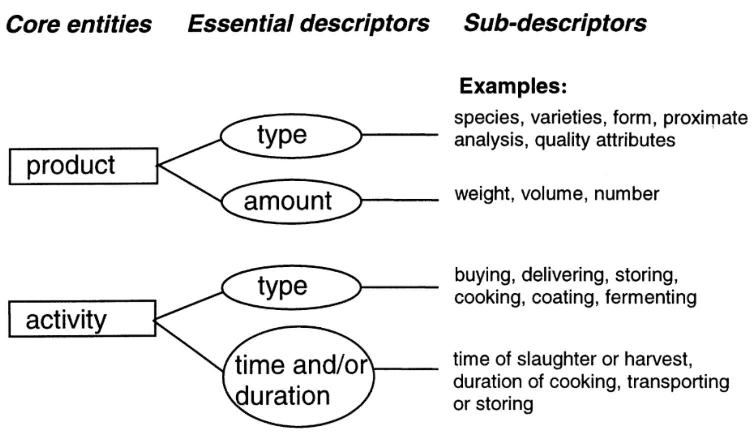

Figure 5: Fundamental structure of a traceability system (Moe, 1998)

Opara (2003) considers traceability to be a part of the overall quality management system that "adds value by providing the communication linkage for identifying, verifying and isolating sources of non-compliance to agreed standards and consumer expectations". A clear definition of a traceability system that includes the analysis of food sample properties or any other way of identifying sources of non-compliance has not yet been found in the literature.

Traceability in itself and related terms such as Traceable Resource Unit (TRU) and the components of a traceability system are also described (Olsen & Borit, 2018). A TRU is a unit with unique characteristics from the point of view of traceability (Kim et al., 1995). One-to-many relationships between traceability codes and TRUs are very common in the FSC due to product conversions, although one-to-one relationships allow for a more powerful traceability system. This is why Olson and

Borit (2018) considered these components of a traceability system and the respective implementation options.

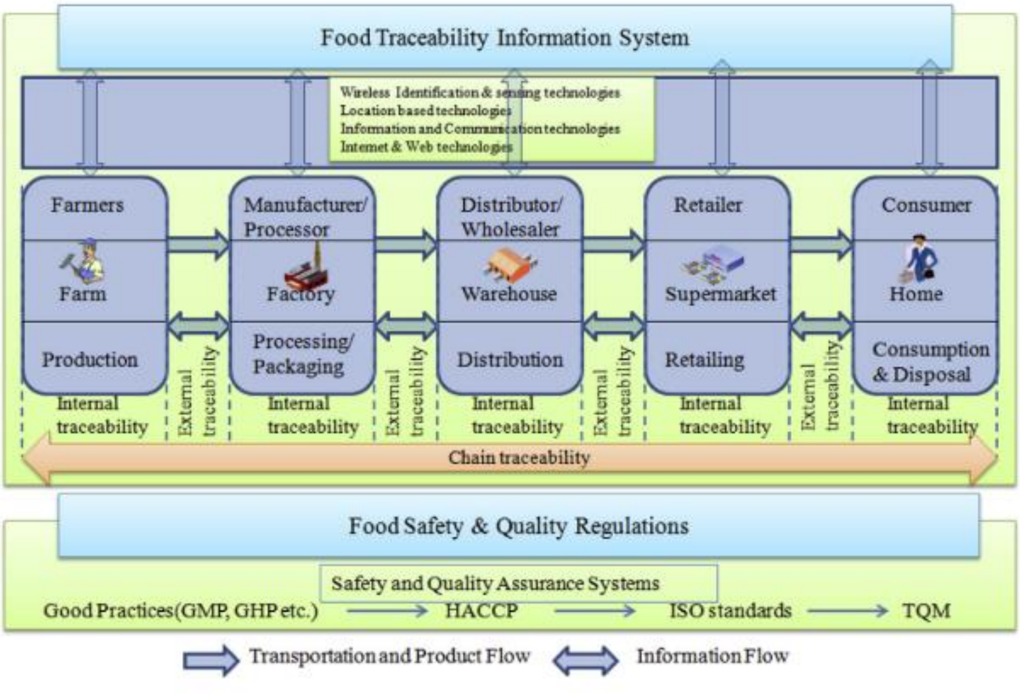

Figure 6: Conceptual framework of a food traceability system (Aung & Chang, 2014)

Figure 6 is an overview of the FSC, including transportation and information flows of the traceability system. It indicates the difference between internal traceability within an organization and external traceability between supply chain partners, in order to obtain 'whole supply chain traceability' (Aung & Chang, 2014). The model also positions regulations and quality assurance systems alongside the core processes of the food traceability information system.

Wireless identification and sensing technologies are also depicted in the diagram, however, it is remains to be investigated which technologies are suitable for the traceability of organically produced fresh produce.

2.3.2.Sensing and detecting

Implementing traceability technology that would be applicable for small-scale farmers, also in the less developed countries, comes with substantial challenges but also opportunities. Integrating emerging technologies (for example DNA fingerprinting, nanotechnology, retinal imaging) into crop and livestock industries could considerably improve the speed and accuracy of food traceability in agriculture (Opara, 2003).

Using sensing technology like RFID at the food item level is mainly aimed at location tracking. But, for example, Mass Spectrometries (MS) analytical techniques can detect chemical residues, like pesticides. Other emerging food technologies can even add 'Uni-molecular sensors' which are a nano-enabled sensors (Langelaan & Silva, 2013). Digital history of organic food assures authenticity to consumers and enhances agricultural food quality (Galvez et al., 2018).

2.3.3.Blockchain application in the FSC

Blockchain technology was invented by Saktoshi Nakamoto (Nakamoto, 2013) and became known to the main public through the peer-to-peer Bitcoin cryptocurrency application. This distributed ledger technology is characterised as being immutable and transparent, providing solutions that are secure, rapid and trustworthy. Transactions that are stored 'on a Blockchain' are seen as records in a block. The block also contains a time stamp and a hash which connects it to a previous block, forming a chain of blocks that cannot be altered. To create new blocks, various ways of verification can be used in such a distributed network, based on a Blockchain protocol (Bitcoin, Ethereum, Hyperledger and many more). This is called a consensus mechanism and is based on a computer algorithm. Consensus is seen as the core of Blockchain, such as *proof of work* and *proof of stake* to confirm the reliability of a recorded transaction (Food and Agriculture Organization of the United Nations, 2018). Like bitcoin, a Blockchain can be either public and un-permissioned, allowing any person to use it or private. A private Blockchain is permissioned in a such way that only a group of known participants, for example in a particular industry or supply chain, can access the ledger (Underwood, 2016).

When using smart contracts with Blockchain, its capabilities expand to helping chain partners to implement and execute business processes across boundaries, also when the trusted third party is not agreed upon (Mendling et al., 2018). A smart contract can be seen as a digitized business arrangement, which can be triggered automatically when certain criteria are met.

The changing role of the middleman, for example a notary or a certification body, often comes into play when Blockchain and smart contracts are discussed. Kim and Laskowski (2018) made a case for the contribution of traceability ontologies to Blockchain design, analysed it and translated this to smart contracts. This made provenance traceability possible on the Ethereum Blockchain platform (Kim & Laskowski, 2018).

Implementing emerging technologies in the FSC to improve traceability comes with issues. Although Blockchain technology has been researched frequently lately, a study comparing eight Blockchain projects affirmed that Blockchain application in the FSC is still rare and information about technical implementation is not detailed (Galvez et al., 2018). Exploring four use cases, the high level of collaboration and commitment necessary to adopt Blockchain technology was seen as a barrier (Hackius & Petersen, 2017).

2.3.4.Traceability technology adoption

Adoption of technology can be an issue, as described for example in the case of Radio Frequency automatic sensing technologies (Mainetti et al., 2013). Limited adoption of sensing technologies by farmers is overcome by proposing a technology solution is against lower cost than using RFID technology, providing easy access to the traceability service for the consumer (Mainetti et al., 2013)

Léger and Johnson studied traceability in French agriculture in 2007 and highlight that an organization's adoption behaviour in the FSC is impacted by its degree of complexity or by the development of their information system. Having access to more resources, large business adopted electronic traceability before it became mandatory in the EU. The research also showed that traceability adoption is initially driven by having tight relationships with suppliers and downstream processors, and after by relationships with retailers. Small firms that can be situated in rural isolated areas, make relatively little use of electronic business applications. Research on traceability system adoption by an organization and the supply chain as a whole remain limited, even though traceability systems have become so relevant in the FSC. It is advised that policy makers provide incentives for firms like these to improve the necessary adoption (Léger & Johnson, 2007).

2.3.5.Traceability standards

European retailers combined their own standards and procedures to develop an independent certification system for Good Agricultural Practice (G.A.P.). It is a programme for quality and food and has become the internationally recognized standard for farm production. Transparency throughout the supply chain guarantees the integrity of your product and reassures your consumers (Global G.A.P., n.d.). The Global G.A.P. Chain of Custody Standard is a certificate for all producers and retailers handling Global G.A.P. certified products and aims to identify the status products throughout the entire process, from farm to retailer (Global G.A.P., n.d.).

Originating in The Netherlands and well known for the barcode standard, GS1 is an independent, not-for-profit organization, that develop international uniform standards for the identification, capture and sharing of data. GS1 unites supermarkets, hardware stores, hospitals and clothing stores, their suppliers and logistics providers for serval industries (GS1, n.d.-a). GS1 also guides the implementation of traceability solutions using the new GS1 Global Traceability Standard, version 2.0. Its provides a framework to ensure the interoperability and scalability of traceability systems, in order for chain partners to easily collaborate and share information for transparency in the entire FSC (GS1, n.d.-b).

By law, all EU food processors need to have a HACCP (Hazard Analysis by Critical Control Points) system in place. This starts from an analysis of food safety hazards within the production process, after which control points and measures are designed to prevent such hazards occurring (HACCP International, n.d.).

ISO 9000 is a quality management system that is widely used by companies all over the world. It is not a product quality standard, but requires that processes are in place to ensure that organisations meet the needs of stakeholders. ISO 9001: 2000 is a standard for a quality management system that can be used by very different organizations and is aimed at increasing overall consumer satisfaction (Besseling & Bergenhenegouwen, 2007).

ISO 22000 specifies requirements for a food safety management system. The standard is exclusively aimed at organizations in the food chain including suppliers of raw materials and animal feed. ISO 22000, on the other hand, focuses on a sub-aspect of consumer satisfaction in the food chain, namely the safety of the products at the moment they are consumed by the consumer. ISO 22000 is an integration of HACCP and ISO 9001. It is generally not necessary to be certified to this standard, but it can give a competitive advantage (Besseling & Bergenhenegouwen, 2007).

2.3.6. Traceability regulations

Food incidents in the past have led to strict international and European regulations, being another reason for the need for food product information (Mainetti et al., 2013). Since 2012, European FSC participants must include information about the manufacturer, seller, importer, storage conditions and preparation of certain foods on food labels. The European Food Safety Authority (EFSA) was initiated to control the General Food Law (European Union, 2014)

EU regulation 178/2002 is the legal framework on food safety and is a prerequisite for a product to enter the market. The aim of the regulation is to protect consumers' health and avoid future scandals. Article 18 requires 'food business operators' to identify from whom and to whom a product has been supplied and to have systems and processes in place to manage this information (Charlebois et al., 2014). This is also called 'one-up-one-down traceability' (Popper, 2010).

Starting July 2010, organic products that are pre-packaged, produced and sold in the EU must have the new mandatory EU logo, replacing the previous voluntary logo (Janssen & Hamm, 2012).

Certification for exporting organic food to the EU, USA and Japan is legally regulated, meaning that the certifying body, the process for certification and the products have to comply with minimum legal standards. Private certifiers in the EU have their own set of (more specific or detailed) standards. These are based on the EU minimum legal standard and may include extra criteria (European Commission, 2011).

A new European organic legislation was published on 14 June 2018: Regulation No. 2018/848. This new organic regulation has several additional features to it (Phytocontrol, 2018) and will come into effect on January 1st, 2021. It is the successor of the current legislation No. 834/2007 (Skal, 2018).

2.4. Research model

The review literature has identified and clarified concepts that are related to the research question. The European organic FSC is similar to the FSC of regular food products. Yet on top of regular food safety regulations such as HACCP, is regulated by European law and certified by assigned certifying bodies per European country. A traceability system can be in place to be able to trace food products, both internally within one organisation in the FSC and externally. This whole chain traceability or 'Farm to Fork' traceability is the object of this research, because traceability of organic food entails information transparency on the origin of food products for the end consumer and other stakeholders.

Concepts that will be researched to answer the main research question are shown in *Figure 7* below. Following the literature review, the type of technology used to work towards food traceability determines a lower level list of factors that impact food traceability. These four factors are expected to show differences in the organic FSC than in the 'standard' FSC.

The research model shows that the choice and therefore the type of technology influences several factors, for example the TRU level that can be tracked, which traceability data can be stored, the level of interoperability and the level of adoption. It is expected that at least these four factors are key in the traceability of organic food in the FSC. The dotted line indicates that other factors may contribute or influence food traceability in the organic FSC.

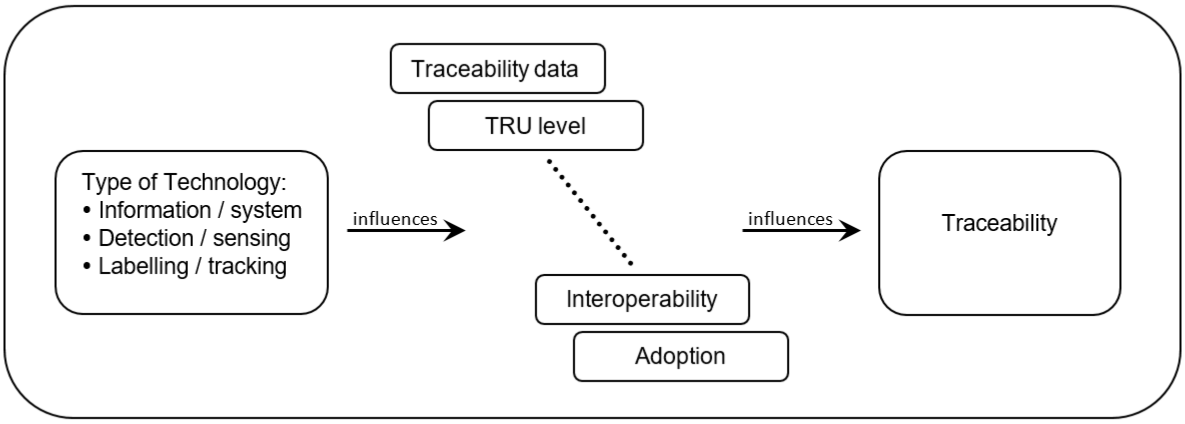

Figure 7: Research model of the research concepts

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3. Research method

The aim of this research is to evaluate current and novel technologies for their actual contribution to food traceability. Research methods per sub question are listed below in *Table 4*. Questions 1 and 2 are answered by further review of existing literature and confirmed by in-depth interviews with people experienced in the respective fields. The third question will identify specific issues in the organic FSC in the literature. An answer to sub question number 4 will be provided by summarising cases from the literature that have investigated the usage of technologies in the organic FSC. How Blockchain can contribute to organic food traceability will be answered by empirical research by case study design in order to bring new insights to existing literature.

	Sub research questions	**Research function**	**Insight**	**Methods**
1	Which core business processes enable food traceability in the organic Food Supply Chain (FSC)?	Describe	Knowledge about the FSC and traceability processes as a foundation for the research.	• Literature review • In-depth interview
2	What is the effect of European legal regulations and standards on food traceability in Europe?	Describe	Discernment of food traceability phenomenon in relation to the most recent regulations.	• Literature review • In-depth interview
3	What are current traceability issues in the organic FSC in Europe?	Describe	Summary of traceability issues to identify factors influencing organic traceability.	Literature review
4	How do current technologies affect food traceability in the organic FSC ?	Evaluate	Overview of current technologies used in organic FSC, understanding of factors influencing organic traceability.	**Case study**: • Case descriptions • Literature review
5	How can Blockchain improve food traceability in the organic FSC and what are considerations in current projects?	Evaluate	Analysis of projects with actual impact on traceability of organic food.	**Case study**: • Case descriptions • Case study interview – 1 per case • Traceability Data analysis – if available

Table 4: Research method per sub question

Following the theory building approach through case studies, the theory that is built is often novel, testable, and empirically valid. Theory building is especially suitable in new research areas (Eisenhardt, 1989). This research can be characterized as a new research area as the research looks behind the hype of Blockchain or any other technology to investigate genuine improvement to organic FSC traceability. Others have not yet answered the research question and following this approach the theory will be induced by evaluating real life examples. In that sense the function of the research question matches the design.

3.1. Literature review

A comprehensive literature review was performed in order to identify the current state of the art regarding food traceability and technology. The literature, which serves as a basis for this paper, aims to reflect the current state of research into food traceability - relevant to the European FSC - that was published in English and peer reviewed. The articles and references were all managed by using Mendeley Desktop and the Word citation plug-in.

The University's search engine HUGO and Google Scholar were used. The search process became more and more structured by using categories in Mendeley. Additional valuable sources of information were identified, because of the backward snowball technique that was used (Wohlin, 1983). Although search terms like Supply Chain were known, synonyms came to light that sometimes extended the search (such as Agriculture / Agri-food / Alimentary). Studies that investigate sustainability of the FSC itself were not included, although the search term 'Sustainability' was later used as a search term for research on the sub questions regarding organic FSC, due to the convergence of these topics. *Appendix 9*: Search criteria literature review shows a complete list of search terms, inclusion and exclusion criteria

In the early steps of the search process, publications initially dated between 2013 and now. To ensure the reference to original sources and a rigorous presentation within the scope of organic food, the search period was extended to 1998 in following steps. Grey literature (government documents, handbooks, etc.) was also reviewed, in cases where such sources provided additional information.

The following databases were used: Elsevier (Science direct, IIMB, HICL proceedings), Matec- EDP, Springer, PLOS-ONE, JRR - International Journal of Research in Engineering and Technology, IEEE, ICMLG - merging (ECMLG (European Conference on Management, Leadership and Governance), Sensors MDPI - Sustainability Logistics, Emerald Publishing and more.

3.2. Multiple case study

Multiple-case study design is preferred when the aim of the research is describing, theory building or theory testing and enables cross-case analysis and the extension of theory (Benbasat, 1987). By using the case study method, the food traceability phenomenon can be researched within its context (Eisenhardt, 1989), in this case of the organic FSC. To fully understand the nature and complexity of this phenomenon, this method paves the road for ‘How’ and ‘Why’ questions (Benbasat, 1987).

Investigating one single case is not appropriate during the research, because it is not merely about one organization, location, person or event. Its focus is on cases in the unique context of the organic FSC. Used to investigate a system that has boundaries and a purpose, it is not applicable due to experimental characteristics that come with emerging Information Technology applications. Such a study researches the whole of all parts functioning together, making it an intensive examination (Yin, 2018), while in this research the aim is to evaluate several cases in order to determine the current practice of the Blockchain phenomena.

Validity of the constructs is secured by using multiple sources of evidence and having the research supervisor review interview topics and the Case list, which are both, used to retrieve case information in a structured way. Because EU law regulates traceability requirements, traceability data from cases are used, where available, to identify data elements necessary for organic food traceability. Data triangulation is performed using these multiple sources of evidence.

Pattern matching across cases and explanation building using documented findings in both Atlas.ti and a collection of reports and notes ensure internal validity. Rival explanations are also addressed, such as, could organic food traceability be obtained without Blockchain technology? In addition, logic models from literature are the basis for evaluating the cases.

The cases are expected to showing similar results, which is a literal replication. Both organic and fair-trade cases, and both smaller and larger chains, are selected to make the results be generalizable beyond this study. For example, one large Dutch retailer will not be considerably different in the way they operate the FSC from another large retailer. External validity is therefore taken into account.

3.2.1.Case selection

A total number of 34 cases were found across industries by searching the internet for blockchain projects, including non-organic and cases outside of Europe. A short list of eleven projects within organic and fair-trade projects was deduced by selecting just FSC projects having to do with organic or fair-trade markets (*Table 5*) to meet the criteria of a minimum of five cases to cover the risk of contacts not being available. Projects highlighted in green were selected for the case study. The five selected pilots were either in flight (currently running), well documented or a project representative was available for interviewing in order to gather data.

Product	Company	Technology / provider	Industry	Status
Chocolate	Tony Chocolony	Blockchain / Chainpoint	Fair-trade	Ended
Citrus Fruit	**Large Dutch Retailer**	**Blockchain / Anonymous**	**Fair-trade**	**In flight**
Rice	**Oxfam (BlocRice)**	**Blockchain / smart contracts**	**Organic and fair-trade**	**In flight**
Tuna	**Fish Tales**	**Blockchain**	**Fair-trade**	**Ended**
Halal food	Halal trial	Blockchain /TE-Food	Halal	In flight
Coconut / Nutmeg	**Fairfood & Versteegen**	**Blockchain**	**Fair-trade (fair payment)**	**In flight**
Seafood	Seafood tracking	Blockchain / Intel – Sawtooth Lake codebase	Fair-trade	In flight
Coffee beans	Moyee	Blockchain / Bext360	Fair-trade	In flight
Oranges, tomatoes	**Carrefour / Nestle / Unilever**	**Blockchain / IBM Food Trust / Hyperledger Fabric (GS1 standard)**	**Partly organic**	**In flight**
Vegetables	Natureta	OriginTrail	Organic	In flight
Tea	Unilever	Provenance	Partly organic	In flight
Carrot, potato	Auchan Retail	Te-Food, QR codes, RFID	Organic	In flight

Table 5: Short list of Blockchain traceability projects

Yin (1983) states that any use of multiple-case study design should follow a replication logic, not sampling logic. This means the number of cases is not as important as the case replication. Here, it concerns literal replication, which means the number of cases is preferably a minimum of 2 to 4 cases.

Each case of a multiple-case study design is carefully selected so that it will show similar or different results (Yin, 1983). This research may include projects that have ended or have been successful, so that any similar considerations for not using Blockchain for food traceability can be uncovered.

3.3. Data collection

For the five cases selected information was collected in a diligent manner. In order to gather as much information as possible, two types of interviews were used. In-depth interviews for sub questions number 1 and 2 and Case study interviews for sub question number 5 concerning the application of Blockchain technology.

Intensive networking took place through LinkedIN, using personal connections in the IT field as well as scouting for new connections. Several different introduction texts were sent by e-mail and customized. People that were invited agreed to participate easily and demonstrated openness during the interviews.

3.3.1.In-depth interviews

Sub questions 1 and 2 required at least one unstructured interview with an expert from the field to verify findings from the literature review. This enhanced the validity of the information found in the literature. The high-level topics and roles interviewed are listed below in *Table 6*.

Label	Roles of representatives interviewed	Interview topics
Expert 1	Director Digital Port Solutions – Port of Rotterdam *(9 years at organisation)*	Supply chain logistics, business processes enabling food traceability
Expert 2	Laywer International Cooperation Agri/Blockchain – *Independent consultant (10 years)*	European legal regulations and standards, controlling/certifying organizations
Expert 3	Business Developer Big Data & ICT Agrifood – *Wageningen Economic Research (10 years)*	Information Technology in organic FSC, elaborating on sensing technologies

Table 6: In-depth interview details

Interview questions were prepared in advance and reviewed by the research supervisor. The interviewees received a list of more detailed topics. All three in-depth interviews were recorded and transcribed, yet not coded. The value to the research did not seem profound. This was because the in-depth interviews acted as a way of validating findings in the literature, while taking manual hand-written notes and summarizing the meetings and finding in OneNote.

3.3.2.Case study interviews

Allowing for structured data analysis and evaluation of the cases, semi-structured interviews were planned. People in Business or IT roles were invited to have details about product information and product traceability arise from the interviews. *Table 7* shows the details of the persons that were interviewed, including their roles and experience in the field.

To be able to evaluate cases using the same criteria, a list of traceability issues identified as traceability issues during the literature review was used as the topic list (column *3* in *Table 7*: Case interview details). Like that, the focus was on the individual experience of the phenomenon in a more quantitative way then using an unstructured interview (Runeson & Höst, 2009).

Case No.	Roles of representatives interviewed	Interview topics
Case 1	Business Development and Project Management Blockchain – Fairfood (1,5 year, experienced in social and environmental projects)	• Complexity • Amounts of data • Costs • Interoperability • Lack of records • Product trace back • Standardization • Transparency • Granularity / TRU level (Traceable Resource Unit)
Case 2	Sustainability Manager – Fishtales (2,5 years, experienced in environmental and sustainable projects)	
Case 3	Project Member Blockchain project – Large Dutch retailer (8 years, over 30 years' experience in FSC)	
Case 4	Private Sector Advisor – Oxfam Novib (1,5 year, experienced in fair-trade, inclusive value chains)	

Table 7: Case interview details

During an in-depth interview about the logistics of the FSC at the Port of Rotterdam with Expert 1 (Port of Rotterdam, personal communication, March, 22nd 2019), it was confirmed that there's still vast amounts of manual paperwork involved in the shipment of containers (that are also used for transport of food). Because Blockchain transforms analogous transactions into transaction blocks, it seemed relevant to add minimizing paper based documents as a driver to start a Blockchain project. This was added to the list of 9 topics. Moreover, because 'Trust' was not identified as an issue in the literature, but is a characteristic of Blockchain, plus frequently mentioned during in-depth interviews, this possible traceability driver was added the list of topics.

During the entire collection process, extensive notes were taken manually and in OneNote. Any insights that occurred during the interviews were documented directly after the interviews in a short interview report in OneNote and in a Word table that holistically showed an overview of sub research questions and halfway insights.

Although this thesis shows a structured research set-up in the order of the chapters, data collection and data analysis alternated iteratively. This ongoing non-linear process is common for qualitative data analysis (Smit, 2002). For example, after the first two case study interviews had taken place, their recordings were transcribed. In addition, before the fourth interview took place, the first two were already coded (see paragraph 3.4). This approach led to flexibility in the topic list during the interviews. For example, during the first interview additional issues around the Blockchain projects were added to the 'Case data' list. Another example is the first Case interview, during which "traceability issues" proved a quite negative way to discuss a Blockchain project and was changed into "traceability issues / drivers". The Case data list also contained a column to identify any connections between traceability issues and IT systems, but issues related to specific systems did not come forth during the interviews.

3.3.3.Ethical considerations

During the research, ethical issues were adequately managed. People that contributed to this research voluntarily participated. Participants were informed of the procedures of the research. The researcher handled case data confidentially, stored within the universities secured network (and not on external devices). For organizations or people that wish for their contributions to not be attributable to their identity, data were anonymized. This was necessary for one larger organization concerned that had already experienced less favourable news coverage. Personal contact information for interviewing was indicated anonymously in any documentation that was shared during the research.

3.4. Data analysis

The interviews were transcribed and loaded into Atlas.ti. Issues around traceability that were already identified in the literature were added as codes to Atlas.ti and used while coding pieces of text in the transcripts. These nine codes were grouped separately to be able to later analyse and compare to any new issues or drivers for traceability, mentioned during case interviews. Open coding was used mostly, where meaning was given to the pieces of text and quotations were used to add observations and notes (Smit, 2002).

After coding the first two interviews, validation of the information that was taken manually during the interviews (Case Data) took place. During the initial coding process, some relationships, or links, between codes were already created to code as structurally as possible, which is called axial coding (Smit, 2002). For example, farmers, producers and suppliers were connected to the code “Chain partner”. Codes were added to new issues around food traceability and used for the third and fourth interview transcripts. Issues during project implementation or reasons to end a Blockchain project were also coded and interrelated. During the coding of the third interview an overview of the now 129 codes was needed to understand the semantic structure of the concepts. This is why all codes were checked for possibly having relationships with other codes. Any future analysis could also be benefited by this step in the analysis process. After all interviews were transcribed and coded, all notes and gathered documents were analysed using Atlas.ti networks, code groups and drilling down to the quotation level to fully understand if interpretations of the results were correct. Case data lists for each case were double-checked against the interview when coding in Atlas.ti.

Not all five selected cases were actually studied. The fifth case that was intended to add information from a European viewpoint was meant to be Carrefour. Several attempts to get in touch through French speaking contacts and sending out a paper questionnaire, did not lead to an interview or the required information. Data gathered to describe the researched cases are listed in Appendix 1 through four. This information is based on multiple sources: interviews, case press releases and website information, case documentation (PowerPoints and images) and physical artefacts (traceability data elements).

3.5. Results and findings

To be able to provide answers to the sub questions, the literature review was continuously used as the fundament for structuring findings. Additional sources in the grey literature were found to be able to answer the sub question about standards and EU regulations. For some sub questions additional practical information from the empirical case study were used as well.

It was initially planned to evaluate individual cases from literature and to describe those cases. However, it proved difficult to discern if cases were actual implementations from literature. Less actual implementations were found than expected as well. Instead, additional articles were found and information from the in-depth interviews added value as well. In order to start the evaluation of technology, the same three categories that were used from the Research model proved structure to the myriad of technological developments.

Before the application to the organic FSC could be assessed, criteria needed to be identified. The traceability issues in the organic FSC, identified while answering the previous sub question, were used for this. Tabulation, as planned, was a good way of making the findings come together. Atlas.ti networks helped to see how codes interrelated, as in for example *Appendix 11: Clusters and relationships with codes*.

The case study on Blockchain applications in the organic FSC followed the same structure to identify which projects actually has traceability benefits. Because all the codes in Atlas.ti were grouped, writing out the considerations for Blockchain technology into Issues/drivers, Blockchain issues and benefits was also a structured exercise. It was of less effort to identify new issues in addition to the literature, because of the Atlas.ti groupings that were created in the analyse phase (*Appendix 10: Drivers for (organic) food traceability, indicated without yellow note icon*).

4. Findings and Discussion

After research of the literature and empirical research of cases in the field, data were thoroughly analysed, which is presented in this chapter. To be able to describe any specific characteristics to organic food traceability, a view of the processes involved is needed (4.1). After the effects of EU law and standards are considered (4.2), specific traceability issues for organic food are described (4.3). An overview of different types of technology affecting on organic food traceability is presented in paragraph 4.4. Concluding findings further describe Blockchain technology application as researched through the case study (4.5).

4.1. Organic food traceability processes

By understanding the steps in the organic food chain, the points where traceability information is captured and possibly sent through the process can be identified. The sub question to be answered is:

Which core business processes enable food traceability in the organic Food Supply Chain (FSC)?

With the knowledge about the regular FSC, organic certification and traceability systems in mind, business process unique to the organic FSC are portrayed. Afterwards, the relationship with traceability is carefully dissected using traceability concepts from the literature.

As demonstrated in the literature review earlier, all chain partners together make up the FSC. Their activities put together, represent the entire chain process of the provision of food. Zooming in on the origin of food, the organic food chain involves the role of a certification body, prior to export and also in process steps further down the chain. The chain partners involved in those steps are the producing farmers, an organisation of farmers or exporting company and the exporter selling the produce.

Looking at *Figure 8* on the next page, the organic production by farmers can be sold in three different ways, either directly to an exporter or through a farmer's organization that in its turn exports the produce or sells it to an exporter. Intermediate organisations such as NGOs may be involved to support the chain partners. The importer takes the goods, often distributing them to traders, for example the processing industry or directly to retailers, that sell to consumers (Koekoek et al., 2010).

The high-level process steps in the organic food chain are buying, bulking, grading, processing, marketing and selling. Verification of food quality has to be guaranteed at every process step. Besides labelling the produce for enabling trace back to the individual farmers or small groups of farmers, ensured, it's a strong recommendation to put a traceability system in place (Koekoek et al., 2010).

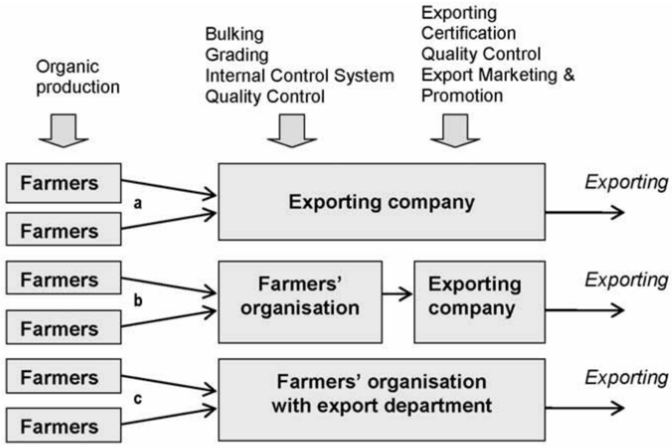

Figure 11: Schematic presentation of an organic chain, including the chain activities:
a. Farmers selling directly to an exporter
b. Farmers selling to their organisation, which sells to an exporter
c. Farmers selling to their organisation, which exports the produce

Figure 8: Schematic presentation of an organic chain (Koekoek et al., 2010)

Bound by the organic certification procedures, farmers and buyers are engaged in a long-term collaboration. The procedures around organic certification already require each actor to record product information. This indicates that some form of sharing information between partners in the chain is already taking place. Chain partners already know each other and know how to communicate with each other, which is an advantage for implementing system for product traceability (Koekoek et al., 2010).

Before the organic food chain even starts, another important event takes place having to do with the origin of organic food. This is the trade in organic seeds. An interview with legal Expert 2, who consults seed traders, showed that farmers may have to buy 'hybrid seeds' which produce more yield but will not produce any new seeds or seeds that will be able to reproduce. This means farmers will have to rebuy seeds annually. In unexplored areas, in for example Africa, crop produce can be organic yet uncertified, because the produce grew from seeds of the previous year and where large chemical companies selling pesticides don't have a foothold yet (Laywer International Cooperation Agri/Blockchain, 2019).

In addition to the earlier literature review, the main traceability requirement to import into the European Union is to record the origin of raw material and the destination of the sold products, including the links between them. "If every actor follows these minimum requirements, products can be traced back to their origin on a step by step basis" (Koekoek et al., 2010, p.19).

Now that the business processes in the organic FSC have been identified, how does food traceability interlace with these processes?

Interviews with Expert 1, working at one of Europe's largest logistic hubs, the Port of Rotterdam (Port of Rotterdam, personal communication, March, 22nd 2019) and with Expert 3 Wageningen University (Wageningen University & Research, personal communication, March 29th 2019) provided insights into the different types of traceability, as previously found during the literature review and how they relate to each other (*Table 8*).

	Internal traceability (Moe,1998) *Vertical* (Lindvall & Sandahl, 1996)	**External traceability** (Moe,1998) *Horizontal* (Lindvall & Sandahl, 1996)
Core entity (Kim et al., 2002)	Inputs matched to outputs	Activity (process): location and movement tracking Product (identification throughout chain) (Bhatt et al., 2013)
Tracing objective	Logistics	Origin verification Provenance verification
Granularity (TRU level)	Pallet, bag, container, truck, train, ship	Single piece, batch
Organic certification	Certification validity	Product / farm (origin) information

Table 8: Organic traceability types, adapted from Moe (1998), Bhatt et al. (2013), Kim et al. (2002)

Several traceability types from the literature were found to relate to internal and external traceability, like product and process traceability. There is also a difference between several levels of granularity (the level at which a unit or TRU is traced) to which traceability solutions need to be adapted (container, batch, single product). Logistic tracing and origin tracing are two different concepts, although not mutually exclusive.

Lindvall & Sandah (1996) use similar types of traceability from a software development standpoint (vertical and horizontal traceability), although Wognum et al. (2011) uses the same terms for a different purpose, that is to say, as dimensions to describe the difference between traceability requirements from legislation (vertical) and information sharing (horizontal).

In conclusion, the organic FSC mainly distinguishes itself from the regular FSC because of the addition of organic certificates, of which the information about the origin of the food needs to be available throughout the chain to ensure whole chain traceability.

4.2. Regulations and standards

The review of literature, international standards and European Commission law has shown that there are many regulations to be taken into account by the partners in the organic FSC. The sub question to be answered is:

What is the effect of European legal regulations and standards on food traceability in Europe?

A research in 2014, comparing 21 countries on a global scale, assessed their traceability programs. The countries in the European Union, Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, The Netherlands, Sweden, the United Kingdom – including the European Free Trade Association (EFTA) countries Norway and Switzerland - scored as ‘Superior’. This means they comply to the EU legislation 178/2002 governing the mandatory traceability of food (Charlebois et al., 2014). European countries that were studied recognized the GS1 coding system, which makes it easier to import into these European markets.

It can be concluded that at the national level EU law is adhered to, but what is to say about the actual practice in the FSC in Europe as far as product data registration by chain partners is concerned? The same research by Charlebois et al. (2014) states that Article 18 of the General Food Law (178/2002), specifying the rules for one-up-one-down traceability, does not specify the type of information that should be recorded by chain partners. According to Wognum et al. (2011) input and output traceability are obligatory, while chain partners are still fairly free in how they realise internal traceability.

Besides the mandatory EU regulations for organic food, it is up to the discretion of an actor in the chain to disclose and share information beyond the one-up-one-down traceability and organic certification requirements. For example, if an organic product does not indicate the certification validity date (which has expired) or the exact location of origin or farm, it could theoretically still be lying in stores, certified as organic.

When asked to describe the role of regulations in the European food industry, the legal expert disclosed that EU law indeed plays a big part and that companies in the European food chain generally comply with EU food law. Continuous lobbying towards regulators by large companies and interest groups was also brought forward as an effect of EU law (Seed trade Contract Consultant, personal communication, March, 12th 2019).

During both the interview with Expert 2 (Laywer International Cooperation Agri/Blockchain, 2019) and the interview with Expert 3 at Wageningen University (Wageningen University & Research, personal communication, March 29th 2019), the perception was that the use of standards inhibit flexibility that comes with innovation.

4.3. Current traceability issues

Traceability issues applicable to the FSC have unfolded from the literature. Although these issues certainly exist when investigating the traceability of organic food, they do not exclusively pertain to the organic FSC. The sub question here is:

What are current traceability issues in the organic FSC in Europe?

This paragraph synthesises five issues into problems with organic labelling (1), third party certification fraud (2), transparency issues (3), the fact that EU law has no requirements for data elements to describe organic origin (4) and the interrelation with internal traceability (5).

The first issue concerns the organic label. The compulsory use of labels in the EU enables the traceability of the origin of products, but also offers assurance of quality in transactions between supply chain partners (Wognum et al., 2011). Several other voluntary organic certification logos are used in many European countries, used by different kinds of organisations, governmental and private organisations. The state of consumer knowledge about labelling was found to be mediocre and was not based on objective consumer information (Janssen & Hamm, 2012). Although not a very recent article, Giannakas (2002) found that organic products may be even be mislabelled and certification is not sufficient for overcoming organic food market shortcomings.

The official certification of organic food by organizations outside of the food chain is also referred to as third-party certification (TPC). Organic trade is built on trust amongst chain partners in the system of certification and in the certification and inspection bodies performing their duties (Munteanu, 2015). Up until the selling point to the consumer, all chain partners handling the organic produce must be certified. Muntenau's review of literature (2015) on the role of the TPC system in Europe shows there is room for improvement. Considering the fact that the certification market in the EU is growing, it is found to still present problems and for inexperienced stakeholders, fraud may occur (Ge et al., 2017; Munteanu, 2015). Information from Case no.4 confirms the literature when the interviewee, often working abroad at several farm locations, described corruption and bribery in the certification process. It was added that certification processes have become inefficient systems themselves that add unnecessary cost to the product (Oxfam Novib, personal communication, May 7th 2019). Hatanaka, Bain, & Busch (2005) claim that TPC may be independent organisationally, but in practice they are not always independent and are operating in social, political and economic networks. The role of TPC and the trustworthiness of the organic certification is a second issue when discussing traceability of organic food.

A third issue is the difference in transparency between certification systems. Besides TCP, other guarantee systems called Participatory Guarantee Systems (PGS) although not officially recognised as legitimate guarantee systems, have become involved in local agro-food ecosystems (Cuéllar-Padilla & Ganuza-Fernandez, 2018). Instead of inspections, all stakeholders involved, including the consumer, define certification standards together and thus determine compliance. In this research, organic food transparency is said to derive from this active participation directly, because all chain actors are cognizant of the process of building trust in the chain. On the opposite side of the PGS system is the confidentiality in the TPC system, which is guaranteed by law, meaning information by operators cannot be published (Cuéllar-Padilla & Ganuza-Fernandez, 2018). This issue in transparency has a direct impact on whole chain traceability because the degree in which chain partners share information is at the heart of food traceability.

Article 18 of the General Food Law (178/2002) does not contain any requirements for internal traceability. Nor does it require that records be kept identifying how batches are split and combined within a business to create particular products or new batches (Charlebois et al., 2014). Hence, the fourth issue is that requirements for the sharing of organic data elements throughout the chain is not regulated by EU law. Although regulations indicate which records need to be kept at the internal level for an individual chain partner or 'operator' (*Appendix 7: EU law information about organic origin*), it is not required to share any information provided by chain partners to obtain organic certification. This can lead to problems in the organic FSC because chain partners may store different data sets and not work within a common data model. It can then prove to be difficult to share information to obtain whole chain traceability, because using different data models will cause interoperability issues between systems.

The role of a large size port in the logistic supply chain was considered to be an important one in the establishment of whole chain traceability, in the extent to which a port uses technology. This can significantly improve throughput times in a port. It can also improve internal traceability, because for example a lost container can lead to perished food or increased cost.

Although internal and external traceability seem like two separate worlds, they do interact if, for example, a chain partner's wishes to prove a products traceability as it changes location throughout the FSC as well as its origin. Thus, issues in the logistic process and the interrelation with external traceability can together be considered as a fifth issue in organic food traceability (Port of Rotterdam, personal communication, March, 22nd 2019).

Finally, perhaps not an issue, but a finding during the entire research and especially the case study is that organic food traceability highly depends on the characteristics of the supply chain, the region or origin and the product itself. For example, Case no. 3 showcased the selection of both a long fruit supply chain and a shorter egg supply chain to be candidates for a Blockchain pilot project to create whole chain traceability (Retailer, personal communication, April, 17th 2019). This is also found in the literature by Wognum et al. (2011) claiming that only in integrated or less complex supply chains, having a limited number of actors and operating over short distances, examples are found of full traceability.

4.4. Current technologies

Findings from mainly the literature have provided descriptive answers to the previous sub questions. Starting from a further breakdown of organic traceability processes, describing the impact of EU law and standards, and concluding with specific issues around the traceability of organic food. Sub questions 4 and 5, however, aim at evaluating the current landscape of food traceability and technology, starting with sub question number 4:

How do current technologies affect food traceability in the organic FSC?

The technologies having an impact on food traceability include both hardware (for example measuring equipment, tags or labels for identification) and software (information systems) (Opara, 2003). There is an increasing array of electronic systems for handling traceability available on the market (Olsen & Borit, 2018). To evaluate how traceability of organic food is affected by the use of Information Technology (IT) three technology categories are considered. They are sensing technology (1), detecting technology (2) and software innovations (3). Sensing technology can be used to improve internal traceability, for example to identify and locate a batch of products as it moves through a warehouse (4.4.1). Detecting technology can be utilized to take samples from products to analyse its composition (4.4.2). Information systems that were found in the literature aiming to improve whole chain traceability are considered to be software innovations (4.4.3). An integrated traceability system could be one where technologies from two or all three categories are combined.

4.4.1.Sensing technology

The first type of technology is known as 'Product identification technology' to Opara (2003) and is predominantly hardware. Based on Opara's research and other scientist's work, Aung and Chang provide an overview of technical instruments that can be applied as sensing technology (*Figure 9*). It includes strengths and weaknesses. Barcodes are considered an established (Mainetti et al., 2013) and popular technology. Radio Frequency Identification (RFID) has numerous advantages for organisations in the FSC to share information rapidly, saving on production and distribution costs. RFID application is paired with high costs and complexity which makes it feasible only for larger organisations (Pigini & Conti, 2017).

Mainetti et al. (2013) conducted a research on the implementation of RFID for product traceability, because it indeed comes with high cost. Their solution combines RFID with Near Field Communication (NFC) technology to connect plants to traceability information in a greenhouse. NFC is a, from RFID derived, wireless connectivity technology that operates at close-range and allows data exchange between two devices (Pigini & Conti, 2017). Although not user tested, the solution proved less costly, because not the entire FSC that was tested was RFID equipped, but a two-dimensional barcode, called Datamatrix, was used instead.

Technical instrument for traceability.

Technology	Description	Strengths	Weaknesses
Alphanumeric codes	Label which includes a sequence of numbers and letters of various sizes, Replaced by bar code	Simple to use and economic	Code read/write not automatic Poor performance High data integrity corruption No standards defined Lack of tie between different actors Cannot collect environmental information (no sensing capability)
Bar codes	Optical machine readable representation of data, Encodes alphanumeric characters and consist of vertical bars, spaces, squares and dots	Simple, more economical and exact traceability	Reading need line of sight Unreadable for damaged labels Can read one at a time by scanner Cannot collect environmental information (no sensing capability)
Radio Frequency Identification (RFID)	Detect presence of tagged objects, Identify or track using radio waves	No line of sight in reading, Can read and write tags Higher data rate and larger memory size Reversible tags, Can read many tags simultaneously	Rely on Reader for data collection, A tag cannot initiate communication, No cooperation among the devices, Can read data within one hop Cost still a burden Limited capability for environmental sensing
Wireless Sensor Network (WSN)	Collect sensing data from physical or environmental conditions, Variety of sensors available for sensing and monitoring	Multihop networking, In-network processing, Can deploy different network topologies, Secure communication among nodes, Longer reading ranges Sensor-actuator networking	Not suitable for identification purpose, Need energy saving techniques for continuous sensing

Figure 9: Fundamental technical instruments (Aung & Chang, 2014)

A QR code (Quick Response code) is also a two dimensional barcode with a larger data capacity than a one dimensional code (Qian, Du, Zhang, Fan, & Yang, 2017) and can also be scanned in order to retrieve additional information or be directed to a website with more information about for example the product.

A single QR coded tag is cheaper than an RFID tag. QR codes were used to improve customer transparency for Cases No. 1 and No. 3 (live projects). During an interview a representative from one of the largest retailers in The Netherlands working on a project to improve the traceability of citrus fruit (Case No. 3), it was stated that if a QR code could be printed "in line". This means QR codes could be used in the production line itself, as is done for meat. Traceability would be made easier, but with for example fruit or eggs that is too costly (Retailer, personal communication, April, 17th 2019). QR code reading for high speed moving processes in the FSC needs further research (Qian et al., 2017).

Wireless Sensor Network (WSN) is a wireless network that can have multiple sensors connected to it in order to collect data. In that sense, it can be considered a technical instrument for traceability, but considering its impact on food traceability, more information is needed about its exact configuration and application in an organic FSC. It is could be interesting, however, to use WSN in combination with one or more other technologies (4.2.4).

After summarizing these sensing technologies, it can be stated that there is an opportunity to improve current product identification and tracking practices to overcome labelling problems as introduced in the previous paragraph (4.3). This could improve the logistic, internal traceability in terms of speed but is therefore not key to improving organic food traceability, which needs trustworthy information about the origin of food products.

4.4.2.Detecting technologies

To determine the quality of organic food within the definition of ‘organic’ of this research, information about the origin of the product, such as farm location is insufficient. Certifying organisations use sampling as one of the instruments during inspection to determine a reliable organic product. For example, Skal is required by EU law to sample 5% of the organic farms each year. When residues of ‘crop protection’ products are found, EU member states need to inform each other to determine the cause and possibly call back products from the market (Skal, 2014).

Opara (2003) calls the detecting technologies ‘Genetic analysis technology’ and ‘Quality and safety measurement technology’ (Hu, Zhang, Moga, & Neculita, 2013; Opara, 2003). The latter can be a chemical analysis to determine the presence of unsafe microbial contaminants (Opara, 2003). To identify pesticide residue on fruits and vegetables in an optimized way, is by using gas or liquid chromatography mass spectrometry. Mass spectrometry (MS) is a fundamental analytical technique for the identification of a myriad of chemical compounds, including pesticides. Scientific methods to universally determine the geographical origin of a product (ingredient) were not found in a research performed three years later by Peres, Barlet, Loiseau, & Montet (2007). The methods used are only indirect methods which often have to be used in conjunction with other methods to increase accuracy (Peres et al., 2007). While there are other sampling techniques, such as DNA product identification and soil analysis, they all rely on analysing equipment that currently is not used as an integral part of organic supply chain processes to determine product origin.

Pesticide residue studies performed by academic researchers and also EFSA have shown a difference in pesticide residues. A quite recent study in 2019 showed that the presence of mixtures of pesticide residues in soils are the rule rather than the exception (Silva et al., 2019) and the EFSA study proved that 6.5% of EU Member States organic food samples, analysed during 2013–2015, contained pesticide residues while this was 44.5% for conventional food samples (EFSA, 2009).

The analytical process, however, requires expensive and sizeable equipment (Stachniuk & Fornal, 2016). It is most often used and seen as a standard for multi residue pesticide analysis in food due to their high sensitivity and selectivity (Hakme, Lozano, Ferrer, Díaz-Galiano, & Fernández-Alba, 2018; Stachniuk & Fornal, 2016). During both an interview at Wageningen University with Expert 3 (Wageningen University & Research, personal communication, March 29th 2019), internationally known for agricultural related research, and the interview with the large Dutch retailer from Case No.3 (Retailer, personal communication, April, 17th 2019) detection technology to validate the origin of a food product was considered to be too costly. Implementing these technologies into the FSC to validate food origin in the first steps of the chain, however, could more accurately determine the origin of food than for example yearly sampling in a certification process.

Interesting developments at Wageningen University and in other places in the world outside of Europe have been taking place overcoming the issue of cost. Expert 3 demonstrated and shared their opinion about molecular scanning using handheld scanning devices, connected to or integrated into smartphones (Sandhana, 2013; The Spoon, 2017), with the advantages of having a solid confirmation of the products origin, a small affordable device and real-time analysis. Application of these technologies is in the early stages and may still lack in precision and accuracy, but could in time revolutionize for example greenhouse sampling of organic products or even consumer verification, also referred to as 'Consumer Physics' (The Spoon, 2017; Wageningen University & Research, 2019).

Looking back at the traceability issues in the organic FSC, detecting technologies could certainly play a role in preventing certification fraud, lead to more transparency than the current certification process and provide a solution for the lack in requirements for the recording of organic data elements. If these technologies continue to develop into affordable applications, regulations and standards could facilitate the use of standard data elements to determine origin.

4.4.3.Software innovations

Software innovations that were found in the literature aiming to improve the information systems to improve whole chain traceability Opara referred to as 'Software technology for traceability system integration' (2003).

Most chain partners of larger size that play a significant role in the handling of organic products use an Enterprise Resource Planning (ERP) system for optimisation of their operations and processes from order to fulfilment. To this day, ERP is having a significant impact on the supply chain. Most companies use point-to-point message connections like XML or EDI (Electronic Data Interchange) to exchange data formats electronically between business processes. More recently, web services offer similar data exchange abilities (Banerjee, 2018). The case study showed that in all cases ERP systems are used, from which data is extracted or connected to the Blockchain solution. In addition, Excel and handheld devices such as cell phones and smartphones are used by farmers to provide information on product origin or fair payment.

Big Data, Artificial Intelligence (AI), Machine Learning (ML) and Blockchain are technological innovations that use data in their own characteristic way, each potentially affecting organic food traceability. The first three all have to do with the analysis of (large amounts) of data.

Using high volume, unstructured data in additional to structured data, often existing within the boundaries of the chain partner's organization, can lead to improved decision making for managing the production process (Serazetdinova et al., 2019), mainly because analysing these often different types and sources of data leads to insights. This may lead to competitive advantages in food supply chain management (Ji & Tan, 2017). Improving whole chain traceability is not an advantage of using Big Data analysis without first integrating the web of vertical and horizontal relationships in the supply chain, including the final consumer (Giagnocavo et al., 2017). The use of data could potentially be of great value though, according to Serazetdinova et al. (2019), for example to develop warning systems to prevent food fraud, but comes with many challenges, similar to the traceability issues already found in the literature, such as interoperability and confidentiality.

Using one type of software innovation (AI, ML or Big Data) exclusively could affect internal traceability by providing insights to optimize logistic decisions, but it will not affect whole chain traceability of organic food. It may, however, be able to overcome the issue of certification fraud by predicting the fraud incidents.

There is agreement among researchers that Blockchain technology can be a powerful tool (Casado-Vara et al., 2018; Galvez et al., 2018; Hackius & Petersen, 2017; Kshetri, 2018) for avoiding food fraud by, for example, assuring geographic and biological origin (Galvez et al., 2018). Traceability at all stages of the FSC can be accomplished. In production, for example, information such as plant cropping conditions and the application of fertilizers and pesticides can be stored in the Blockchain (Galvez et al., 2018). Research by Ge et al., (2017) resulted in a Proof of Concept which demonstrated the feasibility of a permissioned Blockchain ledger and smart contract with the aim to store basic information about certificates.

Considering the issues from paragraph 4.3 around organic food traceability, by design, Blockchain seems able to affect whole chain traceability of organic food. Because Blockchain transactions are immutable, it creates trust between chain partners. Once these are stored using Blockchain technology, transparency is created throughout the chain. There is no need for third party intermediaries with Blockchain technology in order to verify or transfer ownership (Dobrovnik, Herold, Fürst, & Kummer, 2018), therefore the role of certifying organisations in the organic food traceability process could change.

If the same data elements to trace organic origin information are used throughout the FSC, required by EU law or not, the consumer can be provided with trustworthy information about the product. The complexity and the scale of the FSC, however, remains difficult, considered from the viewpoint of literature.

4.4.4.Technologies combined

Looking at the three technology types separately underpins their function and contribution to food traceability, but may not reveal their full potential.

Kshetri (2018) compared 11 cases and considers Blockchain to have more impact by integrating IoT, even without deployment of sensing devices, reading hardware or any process to attach tags. This view conflicts with the proposition for the use of sensing devices to enhance traceability in other research, ranging from a common smartphone (Mainetti et al., 2013) to DNA based techniques (Aung & Chang, 2014) and to component separation techniques (Galvez et al., 2018). Casado-Vara et al. (2018) proposed a model involving Blockchain, smart contracts and a Multi Agent System (MAS) to coordinate the tracking of food in the agriculture supply chain. A MAS is considered as a computerized system, composed of multiple interacting intelligent agents. Each link in the supply chain has its own agent which is synchronized in the Blockchain to coordinate the tracking of food in the agriculture supply chain (Casado-Vara et al., 2018).

The Internet of Things (IoT) creates connections between machines and could enable the automation of traceability. IoT applications are a trend that will affect supply chain management, according to Kshetri (2018) and Accorsi, Bortolini, Baruffaldi, Pilati, & Ferrari (2017). The combination of IoT, (RFID) tags, sensors and barcodes make the tracking of the location of a product, package and shipping containers throughout the chain possible. IoT allows for an enhanced, real-time tracking of product from their origins, having a focus though on internal traceability.

The plethora of technologies can be used in many different configurations to improve organic food traceability. The findings above do, however, provide an overview of how they can be applied to organic food traceability (*Table 9*: Overview of technologies applicable to organic FSC
Table 1).

Organic food traceability issues	*Sensing technology*	*Detecting technology*	*Software innovations*	*Technologies combined*
Labelling problems (errors, not informative)	✓		IoT	✓
Certification fraud		✓	AI, ML, Big Data, Blockchain	✓
Certification / Chain Transparency		✓	Blockchain	✓
No EU organic data recording requirements throughout chain		✓	Blockchain	✓
Impact of logistic traceability	✓		AI, ML, Big Data, IoT	✓

Table 9: Overview of technologies applicable to organic FSC

During the interview with Expert 3, a discussion about IoT (sensor) data and Blockchain technology led to the insight that if validation of data going into the Blockchain is done adequately, a FSC can initiate steps itself and run on its own. Autonomy as a characteristic of Blockchain technology, which is similar to Industry 4.0 could be an advantage to traceability. If molecular scanning can identify pesticide levels in organic food, yearly sampling to ensure certification compliance versus scanning and tracking a single product could severely influence the role of the certifying organization. A certifying body could for example be involved in the calibration of scanning equipment instead of the certification procedure (Wageningen University & Research, 2019).

4.5. Blockchain traceability and considerations

Blockchain application in the FSC is sometimes referred to as a hype due to its complexity and lack of understanding of how the technology actually works. It remains to be seen if Blockchain is all it promises to be. In order to evaluate current Blockchain applications for their impact on organic food traceability, findings from the case study are summarized and presented in this paragraph. The fifth sub question is:

How can Blockchain improve food traceability in the organic FSC and what are considerations in current projects?

Before evaluating cases for their contribution to organic food traceability, possible organic data elements are presented (4.5.1). Findings as to actual improvements to organic food traceability are shared next in paragraph 4.5.2. The final sub paragraph outlines considerations for using Blockchain technology in the organic and fair trade Blockchain projects investigated (4.5.3). To allow for full comprehension of the findings, the final list of cases consists of:

Case No. 1: Fairfood, Blockchain project with Verstegen spices (live) – Fair-trade & organic
Case No. 2: Fishtales, Blockchain project, Pole and line caught tuna – Fair-trade
Case No. 3: Large retailer, Blockchain project, citrus fruit – Rain Forest Alliance (RFA)
Case No. 4: Oxfam Novib, Blockchain project, organic rice – Organic & fair-trade

Case No. 3 requested to remain anonymous, while the other three cases did not have this requirement. Data gathered to describe these cases are listed in *Appendix 1*: Data Case 1 - Fairfood through *Appendix 4*: Data Case 4 - Oxfam Novib.

4.5.1.Data elements

Because Blockchain stores transactional information and EU law has no requirements for organic data elements, it is worth investigating which data elements qualify for traceability improvements.

The case study was able to retrieve examples of data elements for three of the four cases (*Appendix 8: Traceability data elements* - case *)*. Case No. 3 and Case No. 4 did not store any particular data elements about the origin of the product, but a reference to the certificate itself. For Case No. 3 this concerned a Rain Forest Alliance (RFA) certificate and for Case No. 4 an organic certificate. For the Blockchain projects of Case No. 1 and Case No. 2 it concerned a longer list of data elements, some of which concern data elements for internal traceability and others external traceability.

The external data elements are categorized into the following origin groups: Farmer, Trade, Transaction, Fair-trade, Geographical, Farm/Fishery, Product and Quality (to store a reference to a certificate). For all four cases, no specific data elements with information about pesticides usage were identified, because they were inherent to the certification itself and were not stored using the Blockchain solution.

Although it is a simple conclusion that information about the origin of a product is either a reference to the entire organic / RFA certificate or a collection of data elements, it indicates the advancement of whole chain traceability. For Case No. 1 and Case No. 2 the Blockchain solution is advanced, because the traceability data itself about the origin of the food follows the transactions stored in the Blockchain, creating true whole chain visibility. For Case No. 3 RFA certification validity is traced and for Case No. 4 a reference to the organic certification is stored. This does provide information from the beginning to the end of the chain to the consumer, but is not as explanatory for the consumer.

When data elements to provide information about a product’s origin were discussed during the interviews, it was said that these data elements could be seen as merely additional traceability data. Meaning that the Blockchain solution may be built or customized to store any required data element

(Fairfood, personal communication, April, 4th 2019), except when connected to detection technology, according to Expert 3 (Wageningen University & Research, personal communication, March, 29th 2019). To adhere to the concepts from literature (Moe, 1998) this entails the selection of sub-descriptors (*Page 21*).

Another finding was that to use Blockchain, chain partners need to agree on which data and data elements (or fields) to capture and store using Blockchain technology. Because the data requirements all need to be determined before building the solution, Blockchain technology is more suitable for waterfall like approaches than agile project management. This aligns with the idea that the use of standards is preferable on one hand to ensure that a common data model can be used, but it leads to less flexibility as far as the project is concerned on the other hand. Adding empty fields, to be used at a later moment in time, could be a way to use Blockchain technology in a more flexible way (Wageningen University & Research, personal communication, March, 29th 2019).

4.5.2.Traceability improvement

The organic traceability issues used to evaluate traceability technology in paragraph 4.4 (*Table 9*) are used once more as criteria to determine if the cases investigated show traceability improvements. Only the criteria proven to be applicable to Blockchain technology are used. In addition, whole chain traceability is discussed due to its importance to food origin traceability, and projects are evaluated for being successful and/or terminated. The issue of non-defined organic data elements was already covered separately in the previous paragraph. An overview the relationship between the cases researched and these issues is represented in *Table 10* on page *51*.

Improvements to internal traceability can technically be established with Blockchain technology and internal traceability maturity could affect whole chain traceability as proved to be an issue (4.4). Yet none of the cases use for example a QR code to optimize internal traceability and the chain process remains largely paper based.

Apart from Case No. 1 and Case No. 3 where respective products nutmeg and citrus fruit are traced from both an origin and (partly) from a logistic perspective, all projects studied had the primary goal to create traceability throughout the entire chain, from end to end, with transparency for the consumer as the main benefit. Therefore, ameliorating internal traceability was not taken into account to evaluate traceability improvements, also because external, whole chain traceability has a stronger focus on the origin of a product.

Firstly, certification fraud is considered to identify any improvements for whole chain traceability. This issue was explicitly discussed during the interview with Oxfam Novib (Case No. 4). Dependency on information gathered by certification bodies was alleviated by the Blockchain pilot project. Instead of TPC inspecting farmers or farmer association's documents, the validation of origin information was performed at the earliest moment possible in the process (Oxfam Novib, personal communication, May, 7th 2019). Since Case No. 1, 2 and 4 also aimed at proving fair payment for farmers or fishermen, Blockchain technology enabled confirmation of payments by traders at the source. For example, nutmeg farmers use an application on their mobile device and confirm each transaction by confirming a text message. Subsequently, a fair-trade certifying process would in this case be superfluous and fraud in that sense would not occur. Another issue could however occur, because it is left undetermined if the information provided to the Blockchain solution is validated.

Secondly, as far as transparency in the certification process and the chain itself is concerned, similarities in all cases were found in the transparency of product ownership. In order to create transparency about the products origin for the consumer, traceability focusses on each chain partner that actually becomes owner of the product, linked to a payment or transaction. It can be concluded that transparency is desired at that level, having highest-level chain partners share transactional information and linking it to information about the origin of the product.

Another interesting finding, having to do with the transparency in the certification process, is that in all cases chain partners operating towards the end of the chain claimed to work with only partners that can meet, for example, fair trade requirements. If, for example, confirmations of payment were negative for (a series of) transactions, it could lead to exclusion from the chain for the trader in question.

Transparency was not always welcomed in the Blockchain projects investigated. In all cases, confidentiality was an issue during the project. Several types of chain partners, farmers, traders and importers initially hesitated to share information, due to fear of losing competitive advantages. Even transparency about the exact location of a farm could risk disclosing critical information about trading relations, of which chain partners did not want their competitors to get a hand on (Case No. 1, No. 3 and No. 4).

The third evaluation criterion aims at ascertaining whether whole chain traceability is achieved by the projects. To do so, the degree of information sharing amongst chain partners is considered. First, it must be clear that for all cases researched, the chain did not consist of more than five chain partners. This indicates that a FSC was selected that was considered less complex. To different extents, chain partners already worked together with a certain amount of trust. Of those five partners, in Cases No. 1, No. 2 and No. 3, the earlier stages of the chain are handled by one ‘umbrella’ organization, such as a company that buys from farmers and produces (locally). Because of this, it was found that initiating the project, deciding on information sharing and data interoperability was made easier. Furthermore, for Case No. 1 and No. 2 the objective was to share information about the farmer or fisherman, while Case No. 3 and No. 4 do not trace the products back beyond the farmers’ cooperation, simply because of the scale of the citrus fruit and rice plantations.

Organic food traceability issues	Case No. 1	Case No. 2	Case No. 3	Case No. 4
No EU organic data requirements	✓	✓		
Certification fraud	✓	✓	✓	✓
Certification / Chain Transparency	✓		✓	✓
Whole chain traceability	✓	✓		
Project live	✓		✓	

Table 10: Organic traceability improvements (case study)

Additionally, during interviews for Case No. 1, No. 3 and No. 4 it was stated that farmers and fishermen gain insight into where food product go to on the consumer end, adding value on both ends of the chain and creating transparency. Before working with Blockchain, this end-to-end inclusion of farmers and fishermen was not yet realized.

The fourth indication for realizing traceability improvements in the organic FSC using Blockchain technology is whether the project continued after the pilot phase had ended. For Case No. 1 and Case No. 3 projects are running in a live environment, accessible for the consumer through their website (Fairfood, n.d.). Both pilot projects have led to the continuation of the Blockchain project and other value chains will be added to those platforms. The pilot project of Case No. 2 did not surpass the conceptual phase, due to adoption issues and difficulties interfacing with the current paper based process. It is not considered a successful Blockchain project in this sense, although using other means transparency were realized. Although considered successful, the fourth pilot project (Case No. 4) was not continued due to other management priorities for chain partners.

4.5.3.Considerations

The considerations for Blockchain technology are described as following. Firstly, drivers for initiating the projects are highlighted and subsequently the issues that remain and were uncovered by the pilot projects are described. The benefits of using Blockchain to improve organic food traceability are summarized as well.

Data analysis using Atlas.ti provides information on the frequency or "groundedness" of codes, meaning it shows how many quotations, or pieces of text, are linked to a code. Of the top 10 of drivers found during the case study (*Figure 10*); information sharing is the top driver. Although not found as a driver in the literature, especially for Case No. 1 and Case No. 2 information sharing throughout the entire chain was important.

Trust is a key characteristic of Blockchain technology. Although expected to be a driver to improve FSC traceability, it was found that for all cases, trust amongst chain partners was already established. For Case No. 3 gaining more trust in its own supply chain did play a role. The project of Case No. 4 also has the objective to demonstrate Blockchain product traceability to other chain partners, to increase their trust in the technology itself. They also learned what is important in implementing Blockchain technology from other projects. For example, the Blockchain project of the retail business (Case No 3.) encountered negative publicity over farmer working conditions back in 2013. This was verified during an interview with the retailer itself (Retailer, personal communication, April, 17th 2019) and also mentioned in an in-depth interview with Expert 3 (Wageningen University & Research, personal communication, March, 29th 2019). This situation, however, dated back to 2013 and the retailer reasserted the fact that working conditions had already been improved since that time.

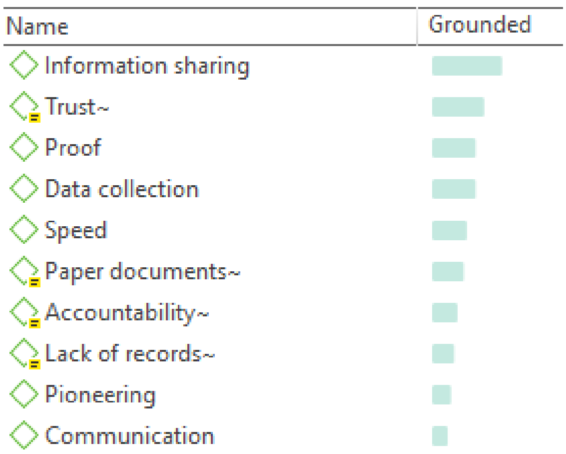

Figure 10: Top 10 traceability drivers

Proof or a guaranty was a driver for traceability at the third position. The driver to use Blockchain technology was to be able to have proof of certification at the source or the products origin. Data collection is related to information sharing, but was also independently important, because Blockchain can be a way to gather information that previously was more difficult to obtain. For some cases (No. 1, No. 2 and No. 3) the fact that these data could be used to trace products more quickly is the fifth driver.

To be able to digitize records or transactions and start to move away from paper-based processes was another driver. Accountability for what happens in the FSC was a consideration to start to use Blockchain as well. Not having any information in certain steps of the process or that tracing products is currently done by making lot of telephone calls and sending e-mails was another driver to want to improve traceability with Blockchain technology.

Finally, being able to pioneer with an emerging technology such as Blockchain was a driver in three of the four cases and improving communications in general was a consideration. Groupings of drivers for traceability are displayed in *Appendix 11: Clusters and relationships with codes* and show the addition of 10 drivers from the case study in addition to the literature.

As mentioned earlier when determining the actual traceability improvements (4.5.2), considerations may also be issues that were encountered during the implementation of Blockchain technology. *Figure 11* shows a list of issues found by the case study.

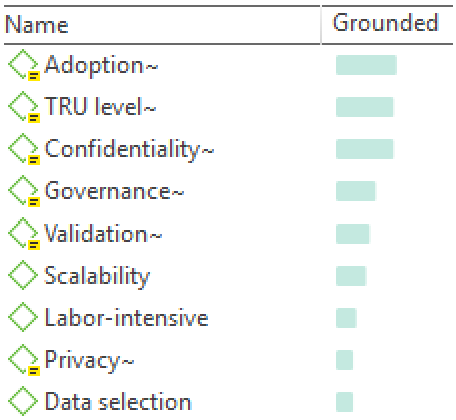

Figure 11: Blockchain issues

Issues around the scalability of the projects were how users can be trained, and how plantations of a bigger scale (2000 farmers) would be able to use these kinds of applications.

For the farmer to enter origin information was considered labour-intensive (Case No. 2 and No. 4). The Blockchain solution was not a replacement of current administrative tasks for fishermen or farmers in any of the cases involved in the research. This means that keeping track of or providing data about the origin of the product is done on paper and using the Blockchain solution.

The last issue of privacy was not seen as a huge concern and solutions were found in several ways. Farmers in the project of Case No. 1 gave permission to share information about for example their farm, products, and marital status, while Case. No. 3 and 4 only share information to the point of the farm cooperation and no personal information through the Blockchain solution.

Besides issues, the Blockchain projects also came with benefits, some of which indirectly discussed when ascertaining the improvements to organic food traceability.

The main benefits are the verification of data, accountability, better risk management, insights into trade transactions, easy data collection and exchange and improved communication.

For the project of Case No. 4 moving from an anonymous product to a product with a data set attached to it was also mentioned as a benefit. For Case No. 3 it was important to ensure consumer satisfaction and gain competitive advantage.

5. Conclusion and Recommendations

This chapter presents the conclusion of the research. To start with, the research objectives will be evaluated (5.1), followed by practical (5.2) and scientific implications (5.3). Suggestions for future research complete this report.

5.1. Conclusion related to research objective

In order to report the conclusions of the research, a re-iteration of the research question is presented:

How can Information Technology (IT) improve food traceability in the organic Food Supply Chain (FSC) in Europe?

According to Bhatt & Zhang (2013) each chain partner must be able to share product information with surrounding partners in the chain, yet also maintain system connections for tracing purposes to guaranty fast and trustworthy flow of traceability information. This definition of whole chain traceability or ‘Farm to Fork’ traceability is the basis of this research.

Current technologies and data exchange formats already allow for information sharing between chain partners, which was found to be the most important driver from the case study on Blockchain application in the organic FSC.

Nevertheless, the issues pertaining specifically to the organic FSC are problems with organic labelling (1), third party certification fraud (2), transparency issues (3), the fact that EU law has no requirements for data elements to describe organic origin (4) and the interrelation with internal traceability (5).

Foremost, when considering the research question from a theoretical and system perspective, the combination of sensing, detecting and software technology has found to be able to contribute to organic food traceability. The organic FSC can be equipped with Blockchain for information transparency, IoT and sensing technology for origin verification and internal traceability, while integrating with chain partner ERP systems.

The empirical results of the case study showed that implementing Blockchain technology could provide added value because of its characteristics of immutability, distributed ledger technology and the ability to exchange data amongst chain partners.

This has shown to create a form of pressure on the FSC. Driven by sustainability objectives like fair-trade or organically produced food, not being able or willing to share information through a Blockchain solution may even lead to finding other suppliers that can meet these objectives. In this way, the ‘chain leads’ who initiated the Blockchain projects, took accountability for the entire supply chain towards its consumers (even though some of these certification services can be outsourced).

Another interpretation of the findings is that the cases researched either selected a chain that was already well arranged, not too complex or did not have more than five chain partners. Case No. 4 even chose a project where the organic rice supply chain had already been improved. For organic and fair-trade cases (not for retailer Case No.3 with RFA certification) the food was already handled by chain operators through a separate production line. Case No. 3 chose two value chains qualifying for Blockchain technology (citrus fruit from South-America and eggs within Europe). This was not just related to choosing simple chains, but also had to do with the fact that contracts and purchase conditions needed to be renegotiated. The alignment of renewing these trade contracts with the shared focus on product traceability throughout the chain, was an opportunity to improve collaboration in the chain. All of these elements of chain optimization have led to faster Blockchain implementations, because teaming up with chain partners can be more efficient between companies that have already (decided to) work together. It is important to recognise that traceability improvement projects can be technology driven and identify issues in the supply chain around traceability as well as improve relationships between chain partners.

Despite theoretical distinctions between various types of food traceability, internal and external traceability are not used as such in the cases researched. At a practical level, the way these two types of traceability are not kept apart as much (Case No. 1 is the best example). The only interaction line between internal and external traceability was found in the selection of which data actually gets ‘into the Blockchain’. This line of interaction is either pushed forward towards the consumer, sharing more information or pushed back towards the first chain links, sharing as little information as possible. These considerations depend highly on the desired levels of confidentiality of chain partners and privacy of individuals.

The key explanation of how Blockchain, as the most qualifying technology, can improve food traceability in the of organic FSC is then, the combination of ‘chain discovery’ and ‘data capture’ and making the relevant choices depending on the characteristics of the organic chain.

Turning this statement around, does the organic FSC need Blockchain in order to achieve whole chain traceability? The answer to that question is simply ‘No’. Whether or not driven by technology, warnings from a Non-Governmental Organisation (NGO), a food incident or the ambition to increase consumer satisfaction, improving whole chain traceability can be done without Blockchain technology. However, it could certainly make food traceability faster and prove to be a good solution for a complex FSC.

Having understandable reasons for discontinuing the Blockchain project, for Case No. 2, a fishery supply chain of small to medium size, product traceability is realized by informing consumers on their website and using their own standard. Fishermen stories and detailed product information is shared, specifically related to the reason why their consumers buy their products, sustainable fishery.

Of course, this does not yet live up to the second part of the traceability definitions used, stating that chain partners need to maintain system connections for tracing purposes for fast and trustworthy flow of traceability information as well. Nevertheless, even for that type of traceability Blockchain technology is not the only solution at this point in time.

In light of EU regulations and standards, the case study found that these are seen as important and especially strict in Europe, but as a wholesaler or retailer responsibility. GS1 was the standard that was best known to participants and knowledge of EU traceability law was limited.

Future developments of standards, technology itself and the evolution of larger projects, like IBM Food Trust, will have to tell at which point in time Blockchain will be the optimum of choices for food traceability. Blockchain does, however, lend itself for an organic FSC where certification bodies play a much smaller role, or even no role at all. However, a (full) replacement of current certification processes is in the foreseeable future is not expected to happen. In this context, chain partners and TPC working together on the certification market in order to share information and improve transparency, could lead to increased trust and might stimulate trade on the organic market (Munteanu, 2015).

The use of Information Technology in the FSC, specifically for the organic food chain has been evaluated. Several cases were evaluated in light of the regulations around food traceability. The objectives of this research were reached and provided many insights for all actors in the organic FSC.

5.2. Practical implications

For chain partners, certifying bodies and farmers it is advised to identify the objective of why organic food traceability needs improvement. This then will be a guide to understand which technology is more suitable and / or if supply chain improvements related to chain collaboration have a higher priority. The advice from several participants interviewed is: start small, first “close the chain” and then start using Information Technology (IT).

The selection of the descriptors and sub-descriptors (Moe, 1998) that need to be captured at each step in the chain needs to be considered carefully. Cautious reflection on the usage of farmer data and consumer data should ensure GDPR compliance. When using incentives to facilitate technology adoption (higher prices for organic products with data, access to financing), farmer dependency on such new models should be researched first.

Efforts of retailers to provide information about the origin of data are exemplary, but consumers should become aware of the actual value of product and origin information, after scanning a QR code and check if it concerns data coming from the source, as close as possible.

The more chain partners involved in the FSC, the more diversity in data and processes, hence the more complex the FSC gets. Experts on EU law and standards should be consulted when in need of clarity of the complex regulations.

5.3. Scientific implications

Many articles were found on food traceability in the FSC and on organic food (quality, certification). This research addresses a gap for where these two subjects intersect. Complex regulations, a complex role of EU regulations and organic certification processes and a disperse collection of Information Technologies, all come together in this research.

Organic FSC concepts were researched regarding the traceability models from the literature (Aung & Chang, 2014; Bhatt et al., 2013; H. Kim et al., 1995; Moe, 1998). Interdisciplinary research to further improve the organic certification process and food traceability can apply the adapted model (*Table 8 on Page 37*).

The drivers for traceability (*Appendix 10: Drivers for (organic) food traceability*) in the unique setting of the European organic FSC can be used for future research on emerging technologies for food traceability, such as Blockchain, to compare with other industries or new cases. The focus on origin information and importance of organic data elements may underpin other research on EU regulations in relation to food traceability.

The research adds value to the body of knowledge on the current status of Blockchain technology, specifically in the organic and fair-trade food supply chain in light of EU regulations. Its shows that Blockchain is currently successfully being implemented on a small scale to obtain whole chain traceability of organic and fair-trade food.

5.4. Limitations

Valuable resources were used to perform this research. The case study method (Yin, 2018) proved to work well for the purpose of this research. Access to sources inside the Blockchain projects made the research obtain its validity. Huge amounts of data were collected though semi-structured interviews, which were used for triangulation of facts found about the cases and findings from the literature.

This research has certain limitations. Firstly, the selection of cases was tenaciously driven towards organic, and half of the cases handle organic food, but none of the Blockchain projects actually stored data about pesticide usage or were able to provide information about the way detecting technologies could be a solution for increased validity of pesticide data (automatically) captured by a Blockchain solution.

Secondly, during the research, several findings about interoperability between Blockchain solutions were found, but this was beyond the scope of this study.

The objective to research case on a European scale, did not fully meet its potential. Dutch cases only were used to evaluate the organic FSC situation in Europe. Considering EU law's mark on the organic FSC, it is believed that the generalizability of the research was not highly affected.

Finally, the scope of the study was predominantly on organic food and the research did study fair-trade cases as well, considering the similarities. While this research tried to keep those two separated from a conceptual point of view, according to Browne et al. (2000) adding additional social criteria to the standards used by the certifying bodies, based on the organic regulatory authorities, could help the FSC move towards an inclusive model (Browne et al., 2000). The research did not explicitly consider the use of Information Technology (IT) to enable this inclusive sustainable food model.

5.5. Future research

Considering the organic FSC, the issues around traceability each deserve more research. Especially considering the complexity of current certification systems.

It remains to be determined how even larger retail FSC's using Blockchain technology, such as IBM Food Trust, are improving whole chain traceability. Information about commercially driven platforms will need to be more accessible in order to do so.

Adoption of Blockchain technology is another research topic worth investigating. Not just on the farmer side, but also how individual users take on the new ledger technology in their day-to-day practices in in handling food traceability.

The development of traceability standards and Blockchain standards and how they relate are other subjects for future research.

The future roadmap for Blockchain for food traceability is worth researching as well. ERP systems are now being extended to Blockchain solutions. Will there be a landscape of private Blockchain solutions, connected to one large public Blockchain?

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Glossary

To improve readability of terminology used in this document, a few abbreviations are listed below in a glossary.

AI	Artificial Intelligence
DNA	Deoxyribonucleic acid, carrying genetic instructions for development of organisms
EDI	Electronic Data Interchange
EFSA	European Food Safety Authority
ERP	Enterprise Resource Planning
EU	European Union
FSC	Food Supply Chain
GAP	Good Agricultural Practice (G.A.P.)
GMO	Genetically Modified Organism
GS1	Independent, not-for-profit organization, that develop international uniform standards
HACCP	Hazard Analysis by Critical Control Points
HUGO	Utrecht University for Applied Sciences (Hogeschool Utrecht) search engine
iFOAM	International Foundation for Organic Agriculture
IoT	Internet of Things
ISO	International Organisation for Standardisation
IT / ICT	Information Technology / Information Communication Technology
MAS	Multi Agent System
ML	Machine Learning
MS	Mass Spectrometries
NFC	Near Field Communication
NGO	Non-Governmental Organisation
PGS	Participatory Guarantee Systems
QR	Quick Response code
RFA	Rain Forest Alliance
RFID	Radio Frequency IDentification
SCM	Supply Chain Management
SDG	Sustainability Development Goals (United Nations)
TPC	Third Party Certification
TRU	Traceable Resource Unit
WSN	Wireless Sensor Network
XML	eXtended Markup Language

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Appendix 1: Data Case 1 - Fairfood

Case Data

General Information	
Case No.	1
Case Name	Fairfood
Country	The Netherlands
Project start	March 2018
Project finish	May 2019
Contact	Anonimized
Food Supply Chain	
Industry	Fresh produce
Organic Segment	Fair Trade
Whole chain traceability	Entire system trough to consumer
Number of partners	5
TRU level	Bag, 50kg, Container
To trace:	1: Product 2: Transaction
Product	Nutmeg
Information Technology	
Blockchain vendor	None, open source development with IT partner
Blockchain type	Public
Sensing technology	None
Tracking technology	QR code
Other technology	ERP, sms, Excel
Standard(s)	GS1
Standard compliance	Yes
EU law compliance	Yes (Wholesaler responsability)
Traceability Data Example	Available

TRACEABILITY ISSUES / DRIVERS	Before project	Fixed by project	New/remaining	Notes *(also see Quotations in Atlas.ti)*	Cluster
Complexity	v			Conversion of product is an issue	Chain
Amounts of data	v	v		Aim to collect data	Data
Costs	~			Not a main driver, Decision to store snapshot not transaction	Process
Interoperability (EDI, API's)		v		Very important	Data
Lack of records		v		Aim to collect data	Data
Product traceback	v	v		Main driver	Process
Standardization				Standard implemented	Data
Transparency	v			Blockchain wallet is unmutable	Chain
TRU level					Data
Paper documents		~		Documents around food safety	Data
Trust				Not an issue, pilot with trusted partners	Chain
Additional drivers:					
Speed	v	~		Blockchain process seperated from regular production line, speed not yet	Process
Information collection and sharing	v			Information about origin / farmer	Chain
Risk management	v			When sourcing in risk areas	Chain
Project / blockchain issues :					
Governance			v	Selection of data, how to manage open source, chain lead	Chain
Adoption			v	In relation to scalability	Chain
Confidentiality				Not an issue, solved by using data ranges	Data
Privacy			v	Farmers formally agreed to data usage	Data
Validation				What are criteria? Farmer validates	Process
Additional issues:					
Data selection			v	Transaction / snapshot	Data
Labor-intensive			v	Moving from recurring confirmation to grievance policy	Process

Appendix 2: Data Case 2 - Fishtales

Case Data

General Information	
Case No.	2
Case Name	Fishtales
Country	The Netherlands
Project start	March 2018
Project finish (ended!)	Oct 2018
Contact	Anonimized
Food Supply Chain	
Industry	Fishery
Organic Segment	Fair Trade / Fair payment / Sustainable fish
Whole chain traceability	N/A (but was the objective)
Number of partners	5
TRU level	Cage
To trace:	1: Product: fish origin = boat identification 2: (Logistic) Process
Product	Tuna
Information Technology	
Blockchain vendor	No Technology selected
Blockchain type	Private (but not built)
Sensing technology	None
Tracking technology	QR code (not implemented)
Other technology	ERP / smartphone / sms
Standard(s)	GS1
Standard compliance	No
EU law compliance	No, but did focus on local law
Traceability Data Example	Available (but project ended in conceptual phase)

TRACEABILITY ISSUES / DRIVERS	Before project	Fixed by project	New/remaining	Notes *(see Quotations in Atlas.ti)*	Cluster
Complexity		NA		Chain was not complex to start with	Chain
Amounts of data	~	NA		Somewhat, aim was to make data more accessible	Data
Costs	~	NA		Costs of obtaining fair trade certification	Process
Interoperability (EDI, API's)		NA			Data
Lack of records	v	NA		And boat identification information	Data
Product traceback	v	NA		Whole chain traceability	Process
Standardization		NA			Data
Transparency	v	NA		Transparency across the chain	Chain
TRU level		NA			Data
Paper documents	~	NA		Not a main driver	Data
Trust		NA		Chain partners already trusted each other	Chain
Additional drivers:					
Accountability	v	NA		Taking responsability by working with fishermen locally	Chain
Project / blockchain issues :					
Governance			~	Data sharing	Chain
Adoption			v	Issues around adoption by fishermen	Chain
Confidentiality			v	Prices, salary	Data
Privacy			~	May have contributed, but can be fixed by not sharing personal data	Data
Validation			v	By using weight of fish on both sides of a chain transaction, validation can be done without blockchain	Process
Additional issues:					
Labor-intensive			v	Blockchain admin on top of regular paperwork	Process

Appendix 3: Data Case 3 - Retailer

Case Data	
General Information	
Case No.	3
Case Name	Anonimized retailer
Country	The Netherlands
Project start	April 2018
Project finish	Oct 2018
Contact	Anonimized
Food Supply Chain	
Industry	Fresh produce
Organic Segment	Rain Forest Alliance
Whole chain traceability	Yes, the first step towards
Number of partners	3 (4 into 1)
TRU level	Nets, cooltanks, blendertank, containers
To trace:	Product / tray / box / batch / pallet / container
Product	Fruit
Information Technology	
Blockchain vendor	Certification & IT outsourced
Blockchain type	Private
Sensing technology	None
Tracking technology	QR code (consumer)
Other technology	ERP & EDI
Standard(s)	GS1
Standard compliance	N/A (by choice)
EU law compliance	No
Traceability Data Example	Not available

TRACEABILITY ISSUES / DRIVERS	Before project	Fixed by project	New/remaining	Notes *(see Quotations in Atlas.ti)*	Cluster
Complexity				Selected simple chain - integrated	Chain
Amount of data				N/A	Data
Costs				Not concerning product callback	Process
Interoperability (EDI, API's)	v	~		Beyond 1st tier supplier no data exchange and mostly for logistics	Data
Lack of records				Not discussed	Data
Product traceback				Not a driver, callbacks are batches due to costs	Process
Standardization			~	Not a driver, flexibility was needed	Data
Transparency	v	v		For customer, start with chain discovery	Chain
TRU level		~		Plays role but not driver	Data
Paper documents		~		Digital is more efficient but not a	Data
Trust	v	v		But only te be able to trust the chain itself, partners were trusted	Chain
Additional drivers:					
Social responsability				Verification certification, acountability towards NGO's	
Proof				Proof of certification before supplier chain	
Pioneering				Couldn't have done the same with EDI	
Accountability				Audits	
Project / blockchain issues :					
Governance			~	Not discussed	Chain
Adoption				Management sponsorship	Chain
Confidentiality			v	Solved by order of data flow	Data
Privacy				No identifying data used	Data
Validation				Outsourced	Process
Additional issues:					
Scalability			v	Validation by farmers not feasible	
TRU-level			v	Batch traceability	

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Appendix 4: Data Case 4 - Oxfam Novib

Case Data

General Information	
Case No.	4
Case Name	Blocrice
Country	Netherlands
Project start	March 2018
Project finish	2
Contact	Anonimized
Food Supply Chain	
Industry	Rice
Organic Segment	Fair Trade & Organic (pestice usage)
Whole chain traceability	Up until cooperation for this pilot (2 x container)
Number of partners	5
TRU level	Big bag, batch
To trace:	Product
Information Technology	
Blockchain vendor	Schuttelaar
Blockchain type	Public
Sensing technology	(Sanorice)
Tracking technology	Label
Other technology	ERP
Standard(s)	
Standard compliance	No
EU law compliance	No
Traceability Data Example	Not available

TRACEABILITY ISSUES/DRIVER:	**Before project**	**Fixed by project**	**New/remaining**	**Notes** *(see Quotations in Atlas.ti)*	**Cluster**
Complexity				Chose the perfect chain	Chain
Amount of data				Not a driver	Data
Costs	v			Certification, claims	Process
Interoperability (EDI, API's)				Not a driver	Data
Lack of records				Not a driver	Data
Product traceback	v			For retailer	Process
Standardization				Not a driver	Data
Transparency	v			For retailer and consumer	Chain
TRU level				Not an issue or driver	Data
Paper documents	~			Not a main driver	Data
Trust	v			Social compliance tool	Chain
Additional drivers:					
Accountability				Chain lead taking responsability	Chain
Communication				Towards customer	Chain
Credibility				Towards customer	Chain
Pioneering				Certification alternative	Chain
Project / blockchain issues :					
Governance				Not an issue	Chain
Adoption				Provided dual language tool	Chain
Confidentiality			v	Issue at first	Data
Privacy / Anonymity			v	Farmer is data owner	Data
Validation			v	Of payment slip	Process
Additional issues:					
Capacity					Chain

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Appendix 5: Traceability drivers and Blockchain issues

Traceability issues / drivers	**Description** *The influence of the issue below on food traceability*
Complexity	The complexity of the food supply chain, the many chain partners working together
Amount of data	The large amounts of data in each step in the process
Costs	Costs that come with tracing products through (parts of) the supply chain
Interoperability (EDI, API's)	Difficult to share data between systems between chain partners
(Lack of /manual) records	Manual entry of data records or no entry of data records
Product trace back	Difficult and/or prolonged product (information) trace back to its origin (e.g. organic/ fair-trade)
Standardization	Lack of standardization or no use of existing standards
Transparency	Lack of transparency of product flow and chain partner involvement
TRU level	Unclear at which level traceability is desired, multiple levels desired
Paper documents	Use of paper documents for crucial product data
Trust	Lack of trust between chain partners or lack of trust on consumer end

Specific Blockchain issues	**Description** *After implementation or reasons not to implement*
Governance	Information management in chain (to distribute power and prevent monopoly)
Adoption	The extent to which (Blockchain) technology is adopted by chain partners
Confidentiality	No data confidentiality (public BC), is about controlling who has access to sensitive information
Privacy / Anonymity	Level of privacy of personal/company data (anonymity, store outside of BC or encrypt)
Validation	Data (from other systems) going into Blockchain has not been validated

Appendix 6: Long list of Blockchain projects / pilots

Pilot / Project	Technology / provider	Industry	Status
Tony Chocolony	Blockchain / Chainpoint	FSC	Ended
Albert Heijn / Refresco	Blockchain / SIM Powerchain	FSC	In flight
BlocRice / Oxfam	Blockchain / smart contracts	FSC	In flight
Fish Tales	Blockchain	FSC	Ended
Wallmart	Blockchain / IBM	FSC	Not Europe
Halal trial	Blockchain /TE-Food	FSC	In flight
UMC Utrecht	Blockchain	Health	
Royal FloraHolland	Blockchain	Plant supply chain	
Mearsk	Blockchain / IBM - Linux Foundatio	Logistics	
Fairfood	Blockchain Provenance	FSC (proof of fair payment)	In flight
Soil Association	Blockchain Provenance	FSC (organic / certification)	In flight
Alibaba	Blockchain / AusPost, Blackmores,	Logistics	
Lockhead Martin	Blockchain / KSI (GuardTime)	Logistics	
MediLedger	Blockchain / Chronicled & LinkLab	Pharma compliance protocol	
Modum	Blockchain & IoT	Pharma	
Diamond theft	Blockchain / Everledger	Diamon industry	
Seafood tracking	Blockchain / Intel – Sawtooth Lake codebase	FSC (fair trade)	In flight
Coffee beans	Blockchain / Bext360	FSC (fair trade)	In flight
Country of Estonia	Blockchain	Government	
Carrefour / Nestle	Blockchain / IBM Food Trust / Hyperledger	FSC (partly organic)	In flight
Choco4Peace	Blockchain / Hyperledger	FSC (fair trade)	Not Europe
Agunity's Agriledger	Blockchain	FSC	Not Europe
Breadtrail	Blockchain / app	FSC	Unknown
Zespri 2014	Oryx	FSC	Outdated
Natureta	OriginTrail	FSC	In flight
Yimishiji	OriginTrail	FSC	Chinese
sweetgreen	Blockchain	FSC	Not Europe
Blockgrain / Ripe.io	Blockchain interoperability	FSC	Australian
Tuna WWF	Blockchain based / Viant	FSC	Not Europe
Unilever	Provenance	FSC	In flight
Olivacoin	Agro Crypto currency	FSC	Unknown
Farmshare	Startup	FSC	Unknown

Appendix 7: EU law information about organic origin

INFORMATION REQUIRED FOR LABELLING	SOURCE
Code number control body (format AB-CDE-999)	REGULATION (EU) 2018/848 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
For operators (closed package, labelled with:)	
Name, address of supplier, and identification of products supplied;.	EU Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling…
Name, address of consumer, and identification of products delivered;.	Same regulation as above
Date and, where necessary, time of transaction / delivery	Same regulation as above
Volume, where appropriate, or quantity:	Same regulation as above
Very helpful if details are kept of any reference or batch number enabling the product to be identified.	Same regulation as above
The operator shall keep the information relating to collection days, hours, circuit and date and time of reception of the products available to the control body or control authority.	Same regulation as above
Conversion to organic labelling information	Same regulation as above
'product under conversion to organic farming' (A conversion period of at least 12 months before the harvest has been complied with)	Same regulation as above
(a) the name and address of the operator and, where different, of the owner or seller of the product;	Same regulation as above
(b) the name of the product or a description of the compound feedingstuff accompanied by a reference to the organic production method;	Same regulation as above
(c) the name and/or the code number of the control body or authority to which the operator is subject; and	Same regulation as above
(d) where relevant, the lot identification mark according to a marking system either approved at national level or agreed with the control body or authority and which permits to link the lot with the accounts referred to in Article 66.	Same regulation as above
Production register	Same regulation as above
Plant production records shall be compiled in the form of a register and kept available to the control authorities or bodies at all times at the premises of the holding. In addition to Article 71 such records shall provide at least the following information:	Same regulation as above
(a) as regards the use of fertiliser: date of application, type and amount of fertiliser, parcels concerned;	Same regulation as above
(b) as regards the use of plant protection products: reason and date of treatment, type of product, method of treatment;	Same regulation as above
(c) as regards purchase of farm inputs: date, type and amount of purchased product;	Same regulation as above
(d) as regards harvest: date, type and amount of organic or in conversion crop production.	Same regulation as above

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Appendix 8: Traceability data elements - case examples

Case	Data element	Data Group	Origin information (External traceability)	(Internal Traceability)
1	Farmer ID	Farmer	v	
1	Payment	Trade	v	v
1	Marietal status	Farmer	v	
1	Date	Transaction		v
1	Price	Trade		v
1	Kilos	Transaction		v
1	Stock	Trade		v
1	Living income price	Fair trade	v	
1	Quantity	Transaction		v
1	Telephone number	Farmer	v	
1	First Name	Farmer	v	
1	Last name	Farmer	v	
1	Gender	Farmer	v	
1	Google maps location	Geographical	v	
1	Farm address	Geographical	v	
1	How many hectares	Farm	v	
1	Product information	Product	v	
1	Other products	Farm	v	
1	EAN product	Transaction	v	
1	Product	Transaction	v	
1	Claims (quality)	Quality	v	v
1	Batch	Transaction	v	v
1	Blockchain Log	Transaction	N/A	N/A
1	Transaction Type	Transaction	N/A	N/A
2	Claim (right amount)	Fair trade	v	
2	Salary	Fair trade	v	
2	Fisherman ID	Fishery	v	
2	Captain ID	Fishery	v	
2	Boat	Fishery	v	
2	# Crew members	Fishery	v	
2	Fish species	Product	v	
2	Catch method	Fair trade	v	
2	Recipient of fish	Transaction		v
3	THT code	Transaction	v	v

Appendix 9: Search criteria literature review

Search terms and key words	Inclusion	Exclusion
Agriculture / Agri-food / Alimentary + Supply Chain	• Publication: Date > 2013 • Language: English • Peer reviewed	Relevance: • Cryptocurrency • Financial • Real estate • Energy • Security • Sustainability (Later included, see *3.1 Literature review)*
Agriculture + Transparency		
Agriculture + Information Technology		
Blockchain + Supply Chain Management + IT		
Blockchain + Transparency + Food		
Blockchain + Organic		
Supply Chain + Systematic		
Industry 4.0 + Blockchain		
Supply Chain + Food + Information Technology		
Supply Chain + Technology + Trends + Trust + Agriculture		
Supply Chain + Traceability + Food		

A cross check on Dutch literature was done using the key words: "Blockchain + voedsel / AFG" but no results were found. Searching for the terms combined with "+ Systematic" resulted in finding systematic reviews of the literature.

Appendix 10: Drivers for (organic) food traceability

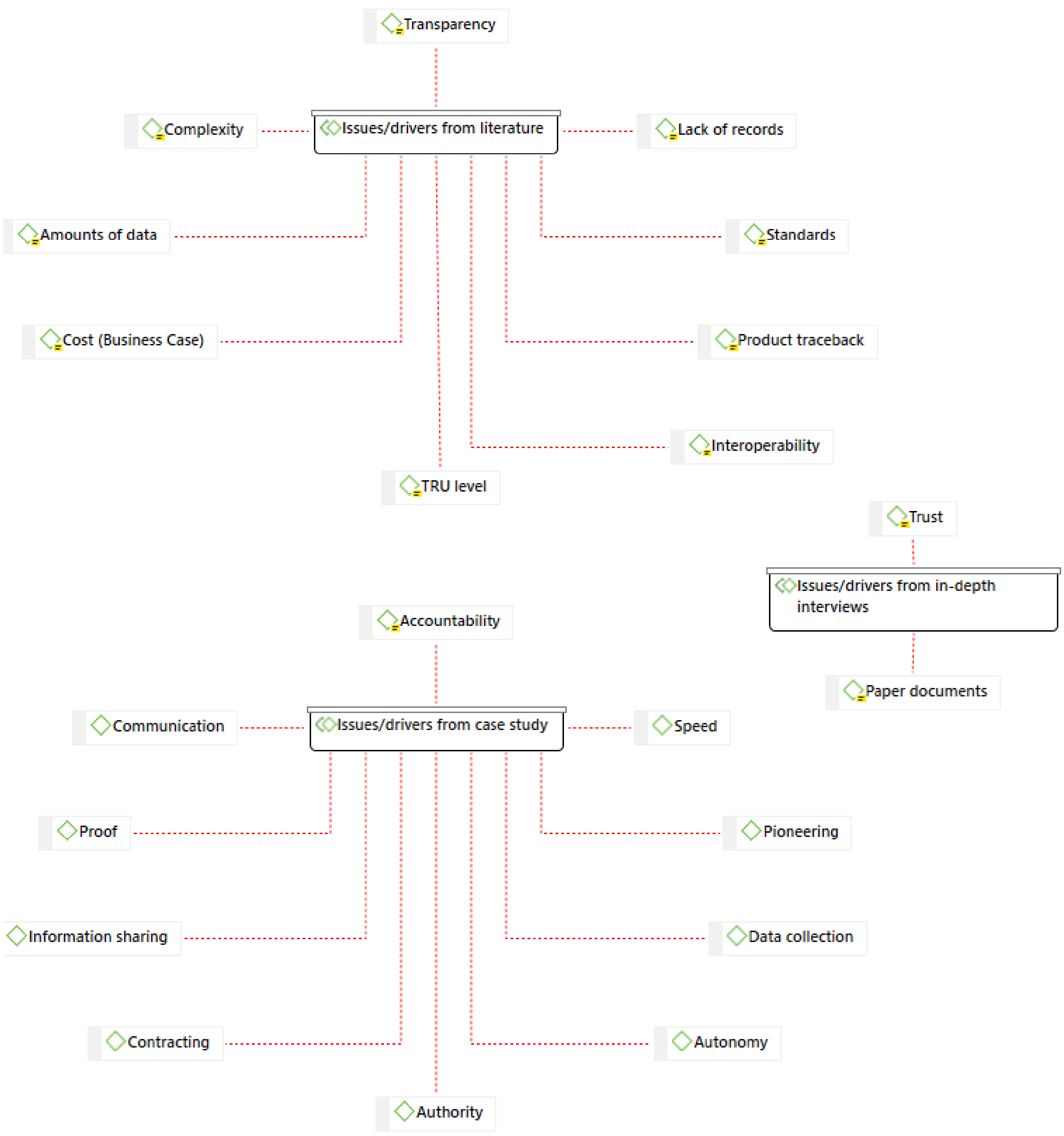
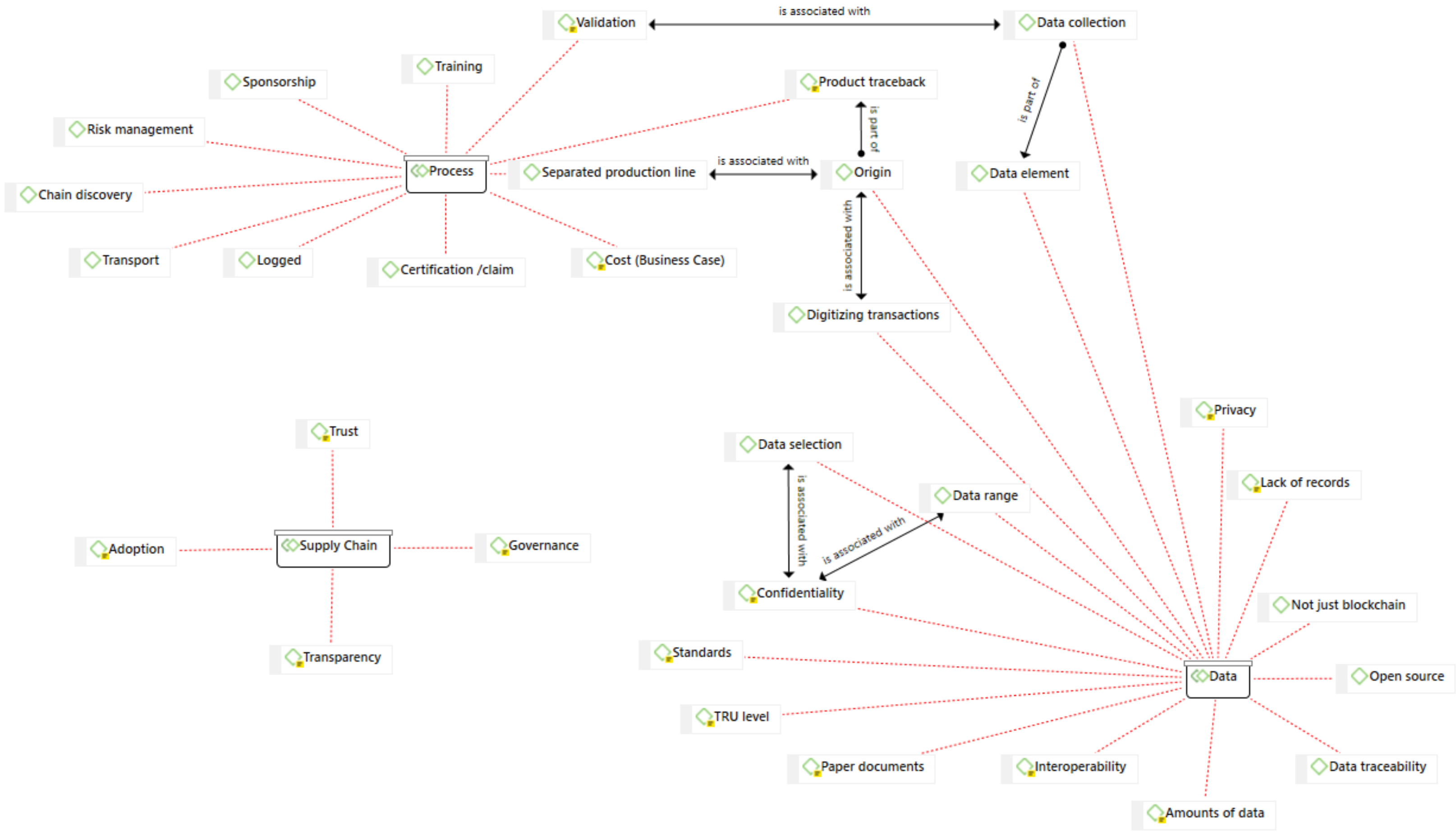


Figure 12: Drivers for (organic) food traceability

Appendix 11: Clusters and relationships with codes



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