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Challenges ans opportunities of using blockchain technology in the food supply chain. Focus on organic food supply chain

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CHALLENGES AND OPPORTUNITIES OF USING BLOCKCHAIN TECHNOLOGY IN THE FOOD SUPPLY CHAIN. FOCUS ON ORGANIC FOOD SUPPLY CHAIN.

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List of Abbreviations

AFSCA : Agence Fédérale pour la Sécurité de la Chaîne Alimentaire

B2B : Business to Business

B2C : Business to Customer

CMR : Convention on the Contract for the International Carriage of Goods by Road

GMO : Genetically Modified Organism

POA : Proof of Authority

POW : Proof of Worf

POS : Proof of Stake

SPF : Service Public Fédéral

Introduction

Since the beginning of human history, every individual needs to satisfy his or her primary needs, the most important being to get fed. If at the beginning this meant gathering and hunting, humans then moved on to agriculture and animal farming for their survival. When he was able to generate profits, he commercialized the food produced. With the development of urbanization, this commercialization increased and became more and more important. It gradually developed and regionalized within markets, then internationalized and finally globalized (Malassis, 1996).

Between the 19th and 20th centuries, a model of industrialized production and trade emerged. Mass production, chemical inputs and the globalization of standardized food production and distribution appeared. This model has developed because of strong growth in the world population, leading to increased food needs. The objective of the food industry has therefore been to manage rising food flows by trying to reduce food prices while ensuring food security (Rastoin and Ghersi, 2010). The companies in this sector, which were characterized by the autonomy and independence of the actors, have become interconnected systems characterized by increasingly complex relationships, a lack of trust between actors, poor transparency of information and limited food traceability (Van der Vorst, Da Silva, & Trienekens, 2007).

At the end of the 20th century, Europe was dealing with the first food scandals, mad cow disease and dioxin contamination. Food safety control systems appeared. Unfortunately, other food scandals followed, such as the horse meat scandal or eggs contaminated with fipronil (Chateau, 2017). Despite Europe's efforts, we are still observing the weaknesses of the food safety control system. Consequently, it would be interesting to study whether, thanks to current technological advances, there might not be a technology to improve the efficiency of this sector, which is so important for good human health. The answer to this question could lie behind the Blockchain technology, known among other things for storing transactions carried out by Bitcoin cryptomoney. Blockchain can be defined in a few words as a technology for storing and transmitting information without a control body. While blockchain was initially seen as the technology that would fundamentally transform the financial sector, its application in other sectors such as fashion, pharmaceuticals and food industry is more and more studied.

The objective of this paper is to analyse the challenges and opportunities of using this technology in food supply chains with a focus on organic food. More specifically, this paper answers the question:

How can blockchain technology be used to improve the exchange of information between the different actors of the food industry?

This work is structured in three parts. The first part includes a literature review in which the concepts of food supply chain, blockchain, and the links between these two concepts are detailed. The food supply chain is defined in the first chapter, its characteristics are detailed, the specific regulations to this sector are detailed with a focus on organic food regulations, its performance indicators and the complexities of the sector are developed. The second chapter deals with the blockchain technology and explains how this technology is structured, with a focus on smart contracts. The third chapter details the links between blockchain technology and food supply chains. The second part describes in the chapter four the construction of an innovative theoretical model (diagram) which illustrates the usage of this technology in the food sector and its application to the organic products. This graphical representation focuses on the digitalization of the information flows of the food supply chains in the blockchain. The last part focuses on the opportunities and challenges of this implementation for the food supply chain stakeholders and the general opportunities and challenges in chapter five. The conclusion of this paper will deal with the feasibility of this implementation.

Chapter 1: Food Supply Chain

This first chapter presents the supply chain in general. The definition of this concept, the various scandals in the sector and the characteristics are covered, the food regulations are detailed, the performance indicators and the complexities of the food industries are explained. All technical terms specific to the food sector are defined in appendix a. The chapter concludes with a representation of the information flows that are essential for the good communication of product information between actors, which is the foundation for the development of the following chapters.

1.1 Definition

Initially, the 'Supply Chain' term was used to describe distribution and logistics operations. Its meaning has evolved over the last 30 years. Nowadays, the supply chain represents a competitive business strategy (Prater & Whitehead, 2013).

According to Mangan and Lalwani (2008) in their book entitled 'Global Logistics and Supply Chain Management' a supply chain is defined as "*a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer*." Based on this definition, we can define a food supply chain as a network of food operators linked together by their operations and activities that produce, transform and deliver food for the final consumer. A simplified food supply chain is depicted in the figure 1 below. In accordance with the definition, the figure shows the network of organizations in a supply chain linked by different flows (financial, goods and information) carrying out different procedures and activities to ensure that the final customer has access to the product.

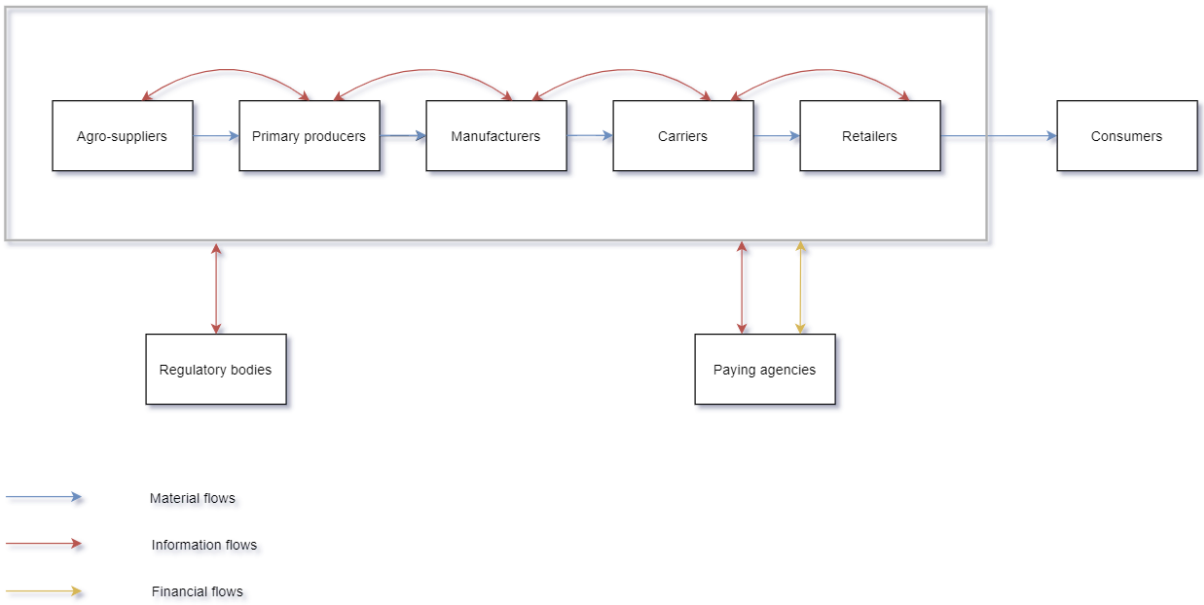


Figure 1: *Representation of a food supply chain (Reprinted from Nakandala, Samaranayake, Lau & Ramanathan, 2017, p.13)*

We decided to represent the food supply chain in this way for several reasons. First of all, it was imperative to emphasize not only the flow of goods but also the financial flows and the information flows. Secondly, the actors operating within the supply chain are represented in a detailed approach, from the input supplier (agro-supplier) to the final consumers, as well as the paying and controlling agencies. Nevertheless, the representation could have been even more detailed, as other actors are often present within this network, such as storage companies, packaging companies, ... The objective is not to represent the most complex supply chain possible but a general supply chain.

In the case of this thesis, the actors taken into consideration will be primary producers, manufacturers, retailers, carriers, paying agencies, food chain control bodies and organic label control bodies. We also consider that only retailers sell to the final consumer (other relationships are B2B) and only manufacturers transform products. We exclude the restaurant sector. Agro-suppliers as well as companies supplying animal feed are not detailed and taken into account in the supply chain network within this thesis. These companies are subject to specific regulations that have not been studied within the framework of this thesis. Moreover, non-EU relations are not detailed. Indeed, considering them meant a large number of customs clearance documents to take into account in addition to documents relating to general purchase and sale operations.

Let's define the role of each operator illustrated.

According to the Regulation laying down the general principles and requirements of food law of 2002, the principal activity of primary producers is the production, farming, field crops and animal breeding, before slaughter. Manufacturers are the operators active in the processing sector. Manufactured products can be biscuits, chocolates, coffee, ice cream, margarine, fruit and vegetable preparations, meat preparations, ... And retailers, in this context, are considered as companies storing and selling food to final consumers.

1.2 Food Issues

The various scandals in recent years mentioned in the introduction raise some questions, such as the recurring food scandals in recent years while a control body is in place. It is questionable whether these scandals do not come from a specific failure or problem within the food supply chain. If we analyse what happened in these different situations, we noticed that some product had to be recalled due to food contamination (Lactalis, 2007 and Eggs with fipronil, 2017) and in other cases due to falsification of information regarding the product (Horse meat, 2013 and Veviba, 2018). This contamination came for the first case from the beginning of the supply chain, i.e. at the level of the producer and in the middle of the chain with the manufacturer. The other case was initiated by manufacturer and intermediaries' actors. This means that food regulations have not been followed by these stakeholders.

We can state that these issues mainly concern producers and manufacturers in this case but they can appear in every food company. What is essential is to find solutions to these problems quickly because the consequences can impact all the stakeholders. A food safety problem can occur in a company without having intended it, or through malicious behaviour. What is important is to be able to recall all the products affected. This is where the situation has become complex. Indeed, it takes time to have access to the information transmitted between the different operators and this lead to considerable difficulty in tracing the products in order to be able to recall them.

1.3 Characteristics

This chapter presents the different characteristics of the food sector. Food safety is discussed briefly, as this point will be developed in more detail in chapter 1.4. The quality of food products is discussed. This chapter also presents the specific characteristics of organically labelled food products. The characteristics of organic products are also detailed in the next chapter on food legislation. Finally, the diversity of food products and traceability are detailed.

1.3.1 Food Safety

The control of food safety in Belgium is the task of a specific body, the Afsca. The objective of this organization is to ensure the safety of the food chain and its quality in order to protect the health of consumers, animals and crops (Afsca, 2017). The Afsca controls all operators active in the food industry. This means that inspections are carried out from the farmer in the production sector to the distribution sector (restaurants, shops, supermarkets, ...) as well as the manufacturers in the processing sector and transporters. There is legislation for each stage (Afsca, 2017).

1.3.2 Food Quality

According to the European Commission (2020), the quality of a product is the most important characteristic when a consumer buys a food product. The detail of food quality deserves to be developed.

Food quality is defined as all attributes that influence the value that consumers place on products. These attributes can deteriorate the quality of a product such as bad smells. They can also improve its quality through appreciable colour or texture (Fao, n.d.). According to Klaus G. Grunert (2005), author of the article 'Food quality and safety: consumer perception and demand', product quality has an objective and a subjective dimension. The objective quality of a product refers to the physical characteristics of the product while the subjective quality corresponds to the quality perceived by the consumer, which is therefore different for each individual (Grunert, 2005). For more details on the subjective dimension of quality, Mr Molnar (1995) gives a definition in his article 'A model for overall description of food quality'. According to him, the subjective dimension of food quality is determined by the sensory properties of the product, its composition, shelf life, packaging, labelling, ... He adds that food safety is very important for a product to be considered of quality (Molnar, 1995). This definition shows that the quality of a product depends on the requirements of each consumer. It also demonstrates the link between product quality and food safety.

The relationship between the objective and subjective dimension is very important. Indeed, each company can use the quality of its product as a competitive advantage, as long as the company can meet consumer demands through the physical characteristics of its product (Grunert, 2005).

1.3.3 Label: Focus on Organic Label

Labels are very present in the food sector. Indeed, they can be used as a measure of quality. Therefore, they are interesting to take into consideration when analysing the characteristics of the sector. In the framework of this thesis, we will focus only on the European organic label. We have decided to consider the Euroleaf because it follows accurate specifications and is regulated by European legislation.

The SPF Economie (2018) gives the definition of a label: "*a label attests that a product or service has been developed in accordance with certain quality criteria or standards. It is also a symbol referring to values. In this way, it can guide consumer preferences. Labels are an important source of credibility if they are monitored by independent bodies. A distinction must be made between official labels, developed and allocated by independent bodies or institutions, and self-declared labels by companies*".

The quality standards and criteria of the organic label refer mostly to the specific characteristics of organic production. Organic production is defined in the Organic Production and Labelling of Organic Products Regulations of 2007 as: "*a comprehensive system of farm management and food production that combines best environmental practices, a high degree of biodiversity, the conservation of natural resources, the application of high animal welfare standards and a production method that respects the preference of certain consumers for products obtained using natural substances and processes.*"

For the production of raw materials, the specifications can therefore be summarized as prohibiting the use of GMOs, ionizing radiation, hormones and the use of antibiotics and restricting the use of artificial fertilizers, herbicides and pesticides. (European Commission, n.d)

For processed products, an additional rule is applicable. This requires that the product must be composed of at least 95% of organic agricultural ingredients. This regulation is illustrated as follows in the figure 2:

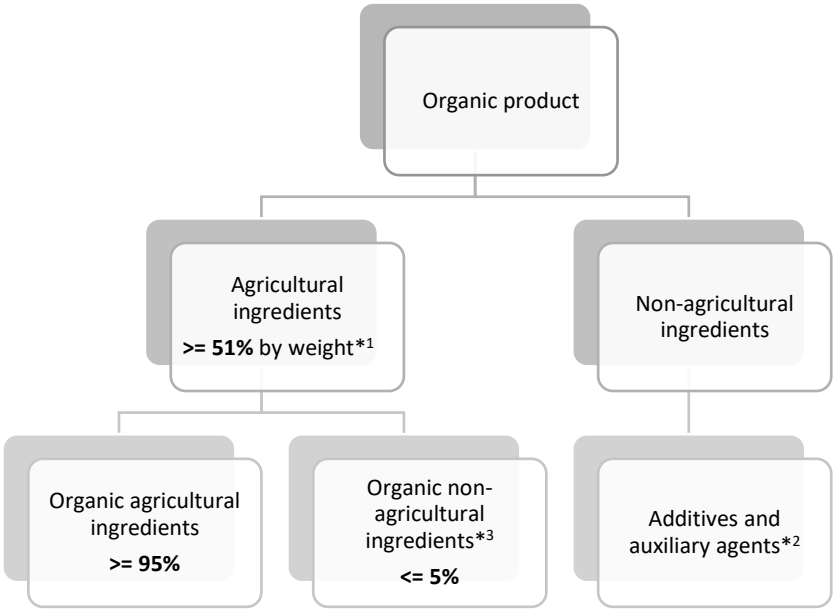


Figure 2: *Requirement specification for organic production of food (Reprinted from Biowallonie,2016, p.5).*

*1 Excluding water and salts

*2 There is a list of authorized additives

*3 Included in the 5% are: specific ingredients defined in the annex 9 of the 2008 European regulation on the production and labelling of organic products. Details of these ingredients are given in appendix b. Some ingredients that have been derogated for a limited period of time are also authorized.

According to Bénédicte Henrotte, member of Biowallonie interviewed in the framework of this thesis, these non-organic agricultural ingredients listed in appendix b are unusual products used in very small quantities. For raw materials not included in the list but which an operator would like to incorporate into his finished product, it is possible to apply for a derogation in order to incorporate them into his recipe. The derogation can be renewed for several years. After several years, it is necessary for the raw material to become organic. Legislation related to organic production is detailed in the chapter 'Regulations'.

1.3.4 Product Diversity

Food products are very diversified. There is a wide range of fresh, frozen, canned, animal and vegetable products. Based on this diversity, two families of products can be identified: perishable and non-perishable products which have different life cycles (Manzini and Accorsi, 2013). This diversity impacts food companies at different levels. For instance, Logistics departments have to adapt the routing of vehicles and schedules according to the

goods being transported. The nature of products can impact their qualities and therefore the health of consumers. Production and Transformation departments are also affected and have to adjust their processes according to each different product (Alimento, n.d).

Moreover, as it will be seen in section 1.4, legislation is also different depending on the nature of the product. For example, a fresh product of animal origin will be subject to stricter regulations than a canned product.

1.3.5 Traceability

According to the Regulation of 2002 laying down the general principles and requirements of food law, traceability refers to "*the ability to trace, through all stages of production, processing and distribution, the movement of a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed*".

The book 'Food Traceability' makes the distinction between internal and external traceability. External traceability refers to recordkeeping requirements for companies in the food supply chain sector. These records are available for regulators conducting trace backs. Operators in the food supply chain have to keep useful documents to control their traceability such as invoices, purchase orders, and bills of lading (Food Traceability, 2019). Internal traceability requires that all operators in the food supply chain record information related to the transformation of their products. This information is also available when regulators control the operator (Food Traceability, 2019).

This same book also adds the concept of tracing backward and forward through the supply chain to understand product movement. The forward trace refers to the path taken by a product in the chronological order of its consecutive movements (Food Traceability, 2019). Tracing forward is needed when a product must be recalled to understand the way it has been distributed. The backward trace is used in the supply chain to find the source of a problem. For instance, with the identification of a lot, it is possible to trace back records related to this lot (Food Traceability, 2019).

All departments in a company need to be involved in the traceability process. For instance, in departments related to Supply Chain and Logistics traceability is key as it is related to movement of products. The IT department is involved in the maintenance of the system used to record the movement of products. In Accounting department, traceability is also important because the movement of goods have an impact on financial flows and for the Procurement and Sales services, they need to have visibility on the customers, the origin and destination of the product.

As it is going to be detailed in the next section, traceability is of a paramount importance for food safety (Food Traceability, 2019).

1.4 Regulations

The legislative and normative framework of food policy consists of food Regulations, Codex Alimentarius and the World Trade Organization (SPF Santé Publique, 2016b).

The Codex Alimentarius was established in 1961 by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO). It contains international norms and guidelines on food product and food safety (SPF Santé Publique, 2016a). The World Trade Organization (WTO) is an organization of 161 members that deals with the rules governing trade between countries on a global scale (SPF Santé Publique, 2016e).

The purpose of this chapter is to set out the different European and Belgian food regulations. This is why we will not go into deeper detail about the Codex Alimentarius and the World Trade Organization.

In Europe, the food legal bases are described in the General food law regulation of 2002, other legal documents complement this regulation. The vast majority of food standards are harmonized at European level and apply in all member states. In accordance with the 2002 Regulation laying down the general principles and requirements of food law, each country controls and verifies compliance with this legislation at all stages of production, processing and distribution through an official control system. Each country also has its own regulations complementing EU regulations. In Belgium, the legal basis for food legislation is the law of 24 January 1997 (SPF Santé Publique, 2016c). A number of royal decrees complete the legal basis of the country. The national food standards are drawn up by the 'SPF Santé Publique, Sécurité de la Chaîne alimentaire et Environnement', with the exception of hygiene standards which are drawn up by the Afsca (SPF Santé Publique, 2016c). The latter is also responsible for the control of food safety as mentioned in chapter 1.3.1.

The objective of food regulations is "*to ensure a high level of protection of human life and health and to protect the interests of consumers while guaranteeing the free movement within the European Union of products that comply with the principles and requirements of food law*" (SPF Santé Publique, 2016c). Organic food production, on the other hand, has its own regulations supplementing the various food standards.

In order to explain the regulations applied to the food sector, we will first detail the responsibilities of the actors in the supply chain. These responsibilities include traceability,

mandatory notification and labelling. We will then detail how a control is carried out within a food company as well as the self-checking systems that must be implemented by each company. The figure 3 below summarises these regulations for each actor in a general supply chain as well as for organic supply chains. All points in this figure are detailed in the following sections.

<table>
<tr><th>Supply Chain/ Operators</th><th>Primary producer</th><th>Manufacturer</th><th>Retailer</th><th>Carrier</th></tr>
<tr><td rowspan="3">General Food Supply Chain</td><td colspan="4">- Afsca registration
- Operator administrative data:
o Approvals (animal products)
o Authorizations
- Obligations related to infrastructure, facilities and hygiene
- Mandatory notification</td></tr>
<tr><td>Input register, output register</td><td>Input register, output register
Internal product traceability</td><td>Input register, output register</td><td></td></tr>
<tr><td>Restricted self-checking</td><td>- HACCP self-checking
- Labelling regulations (Presence of specific information with the product)
- Product identification: new or identical to the previous one</td><td>- HACCP self-checking
- Origin:
Fruits and vegetables, meats, fishes</td><td>- HACCP self-checking
-The products transported are identified
-Mandatory documents are present
-Transport temperatures are controlled</td></tr>
<tr><td>Organic Food Supply Chain</td><td colspan="4">- Notify the competent authorities of their activities to obtain the certificate of organic production and labelling
- Controlled by independent bodies</td></tr>
</table>

***Figure 3**: Summary of regulations*

1.4.1 Responsibility

Under the 2011 Regulation on the provision of food information to consumers, every operator from the producer to the distributor, active in the food sector must comply with the legislation applicable to its sector of activity. This means that they must guarantee the traceability of all food products at all stages of the supply chain, carry out the immediate recall or withdrawal of food products if there is a risk to the health of consumers and inform the Afsca and consumers when necessary. Each operator selling food on its behalf must also include on the product the required information and ensure its accuracy.

Under the Royal Decree of 2003 on 'Autocontrôle, notification obligatoire et traçabilité dans la chaîne alimentaire', each operator must identify himself to the Afsca and his details will be recorded to ensure the correct operation of the control system in the companies. In addition, in order to run specific activities, an authorization or approval is required. Among the

establishments requiring approval are slaughterhouses, cutting plants, those manufacturing meat products, etc. Establishments subject to authorization are companies producing, processing or distributing food products, or trading, transporting and preparing meat, etc. (Afsca, 2019a).

According to the organic production and labelling of organic products Regulations of 2007, organic food operators must notify their activities to the competent authorities in order to obtain the official certificate declaring that they comply with the organic production and labelling rules.

1.4.2 Traceability

Food traceability includes traceability of incoming products, internal traceability and traceability of outgoing products. This is achieved through the identification and registration of companies and the identification and registration of products (SPF Santé Publique, 2016d).
Under the Royal Decree of 2003 on 'Autocontrôle, notification obligatoire et traçabilité dans la chaîne alimentaire', food operators have systems and procedures to identify companies that have supplied goods to them and companies to which their products have been supplied.

They must also have systems and procedures in place to record incoming products, outgoing products and the relationship between incoming and outgoing products in order to establish the internal traceability of transformed products. For incoming products, the information required for registration is: nature, identification, quantity, date of receipt and identification of the operator supplying the product. For outgoing products, the information required for registration is: the nature, identification, quantity, date of delivery and identification of the business unit taking delivery of the product.

The identification of business units is done by registering an identification number recognized by the Afsca. Products, on the other hand, must be registered using the same identification given to them by the business unit delivering the product if the product is not transformed.

According to Mr Eric Sonnet, a member of the General Direction of Economic Inspection at the SPF Economie, the requirements concerning the traceability of food products depend on the processing carried out. For limited processing, the production process links the input product and the output product. For full processing, internal traceability is necessary. It is required to record the day and time of processing as well as the raw materials used and the finished product.

1.4.3 Mandatory Notification

Withdrawal of food products from the market occurs when an operator considers that the product which has been imported, produced, manufactured or distributed does not comply with the food safety rules. If the food product is no longer under its direct control, the operator shall inform the Afsca of this withdrawal. The Regulation laying down the general principles and requirements of food law of 2002 stipulates that when the product has already reached the consumer, operators in the food chain shall recall the product and inform consumers of the potential hazard. The Royal Decree of 2003 specifies that when a problem arises within a company, compulsory notification is not necessary if the self-checking system in place eliminates the hazard.

1.4.4 Product Labelling

As mentioned in Chapter 1.4.1, it is mandatory to mention specific information on each manufactured food. In accordance with the 2011 Regulations on the provision of food information to consumers, the mandatory information includes: the name of the product, list of ingredients, net quantity, use-by date, name and address of the operator, nutritional declaration and allergen information. However, it is important to mention that for some products, the list of ingredients is not mandatory. These include cheese and butter for instance.

Unlike manufactured food products, fresh fruit and vegetables are not required to have an ingredient list or an expiry date. However, it is mandatory to mention the country of origin. For meat, an ingredient list is not mandatory when the product consists of only one ingredient and the name of the product is identical to the name of the ingredient. In a similar approach, the origin must be mentioned for fresh, pre-packaged, prepared, frozen or deep-frozen meat (place of rearing and slaughter). The specification of the identification number (Sanitel number), the place of slaughter and place of cutting are compulsory for beef. For fish, the list of ingredients is not useful either. However, its commercial name, its scientific name, the de-freezing date if frozen, as well as the production method and origin are indicated (Wallonie agriculture SPW, 2018). Eric Sonnet, director of the economic inspection at SPF Economie, stresses the importance and the obligation of mentioning the origin of meat and fish products and also of other specific products (fruit and vegetables) towards the consumer to prevent him from being misled.

The 2007 Regulation on organic production and labelling of organic products stipulates that organic products must include additional information such as the code number of the operator's inspection body, the organic production logo and the location of the agricultural raw

materials used for pre-packaged foodstuffs (in the form: EU agriculture, non-EU agriculture, EU/non-EU agriculture).

1.4.5 Control

As mentioned in the preceding chapters, the Afsca is the body that controls each operator active in the food industry. There are nine local control units in Belgium, more or less one for each region. In addition, each local unit includes three subunits depending on the sector: primary sector, processing sector, distribution sector (Afsca, 2019c). These controls are organized using 'checklists'. Article 14 of the European Regulation of 2017 on official controls and other official activities performed to ensure the application of food and feed law details the content of the checklist, which includes the control of the self-checking systems put in place by each operator and the results obtained thanks to these systems (the self-checking systems are detailed in the following chapter), the inspection of: the infrastructure and facilities where food is handled, all materials in contact with products intended for consumption, packaging materials, equipment and means of transport. Traceability, labelling and hygiene are also controlled. Interviews with operators and their staff are carried out and sampling is made on some products. It is important to specify that, for the labelling of food products, the Afsca shares its competences with the SPF Santé Publique (SPF Economie, 2019).

The frequency of inspections depends on the operator's sector of activity and the risk associated with the various products. The Afsca considers that there are three different sectors, the primary sector, the processing sector and the distribution sector. For the first sector, relating to animal and plant production (not including slaughterhouses), the frequency of controls is low. For example, the frequency of control of a farm is every eight years or every 12 years if the self-checking system of the operator is certified (Afsca, 2019b). The processing sector, relating to industries whose B2B activities account for more than thirty percent of turnover, has a higher inspection frequency. For example, a manufacturer of biscuits products is checked every 2 years. Indeed, these operators handle and distribute a lot of products. Moreover, when the origin of their products is of animal origin, the checks are much more frequent (four times a year for the control of a manufacturer of meat products) (Afsca, 2019b). The distribution sector, i.e. retail businesses whose relations are mainly B2C, are inspected once every three or four years depending on if they manufacture products on the spot or not (Afsca, 2019b).

Organic production involves additional control measures. As stipulated in the 2018 Regulation on organic production and labelling of organic products, control frequencies are carried out every year or every two years if no fraud has been detected during the last three

years. These controls are carried out by independent bodies accredited for the control and certification of organic products. Organic production, being closely linked to agriculture, is a regional competence. As a result, each region in Belgium has its own inspection bodies. In Wallonia, there are 3 certification body (Certisys, Quality Partner and Tüy-Nord Integra). As with all food products, the control of organic products is conducted in order to verify that each product complies with the European food and organic production rules. The control includes visiting the company, the farm, taking samples, checking the raw materials and checking the conformity of the labels (Biowallonie, 2016).

1.4.6 Self-Checking

According to the 2011 Regulation on the provision of food information to consumers and the Royal Decree of 2003, the self-control system must be based on the system ″Hazard analysis and critical control points″ (HACCP system), which makes possible to identify, avoid and eliminate any hazards. For primary sector operators, this latter must focus particularly on hygiene requirements and must keep a register of the various risk controls relating to their production. For operators keeping animals or producing products of animal origin, this register must contain certain specific information such as origin, medicines used, diseases, feed used (identified with their lot numbers), ... For plant production operators, the registers must mention the pesticides used, diseases, ...

1.4.7 Performance Indicators

According to researchers from Waggeningen University in their article ‘Performance measurement in agri-food supply chains’, there are four performance indicators for food supply chains, the degree of efficiency, flexibility, responsiveness and product quality (Aramyan & al., 2007). Efficiency identifies the resources used, using various measures such as production costs, profit and stocks. Flexibility assesses the ability of the supply chain to respond to changing environments and customer service requirements. Flexibility is measured through customer satisfaction, delivery flexibility, volume flexibility, reduction of backorders and lost sales. The third indicator, responsiveness, measures the ability to deliver requested products with a shorter lead time. Responsiveness indicators are, for example, product delay, customer response time, shipping time, etc (Aramyan & al., 2007). The last indicator, food quality as a performance measurement tool, includes the quality of products and the quality of procedures.

1.5 Complexity of Food Supply Chain

This chapter discusses the different characteristics of the food industry sector that make food supply chains even more complex than those of other sectors.

As discussed in chapters 1.3.1, 1.3.2 and 1.4, quality and safety in the food sector are very important characteristics. Quality is an important characteristic in all sectors. What is specific to the food sector, however, is that time and environment can affect the quality of food products. For example, poor packaging, a problem during loading, poor temperature control or even poorly managed humidity can compromise the quality of a product. In some cases, this can even lead to produce contamination (Manzini and Accorsi, 2013). That is why there are many rules to ensure consumer safety. These are detailed in section 1.4.

As mentioned in the chapter 1.4.2, the need for traceability is part of the rules to ensure food safety. Each business must keep records of the information requested in order to guarantee traceability. According to Pierre Denis, head of transformation sector in Afsca, the information is transmitted through different documents depending on the business. According to the companies interviewed, this can be delivery notes, purchase orders, invoices or technical data sheets. Each one does not contain all the information that a controller would ask to see. Pierre Denis adds that these documents are often scanned several times and handwritten. In addition, each company may give a different identification to its product. This does not facilitate good traceability. Traceability is particularly complicated for fresh products with a short life cycle, as they are often sold in bulk with little information about the batch from which the product came. Moreover, these products are already consumed when the investigating authority wants to check them. (McEntire, & Kennedy, 2019)

Another challenge, which is not a feature specific to food industry but for companies in all sector, is the shift from domestic to international markets. As a result, the focus is no longer simply on producers but on the entire supply chain. This globalization of markets makes collaboration between the different players in the food industry more complex and trust is difficult to achieve (Van der Vorst & al., 2007). Although in the food sector, good collaboration is crucial as the value creation of each product depends on each player. Moreover, ensuring food safety and good traceability is only possible through good collaboration (Handayati & al., 2015).

1.6 Information Flows

In the context of this thesis, it is important to detail the information flows existing between the operators because these flows are at the heart of the schematic model of blockchain usage in food supply chain that we wish to build. The illustration below shows the simplified information flows, from the signing of the sales contract to the sending of the invoice. We consider three actors in a food supply chain in the figure 4. Moreover, the documents are numbered to represent the order in which they are sent. This representation is based on several interviews with companies completed by phone. Among those interviewed were the Operations Manager of Belourthe, the CEO of Sainte Nitouche and the CEO of SalmInvest. They were conducted in an exploratory approach. These inverviews enabled an understanding of the way in which information flows between the actors in a supply chain works. The questions were prepared in advance but led to further questions during the interview based on the stakeholders' responses. The transcripts of the interviews conducted with each of these companies are available in appendix f.

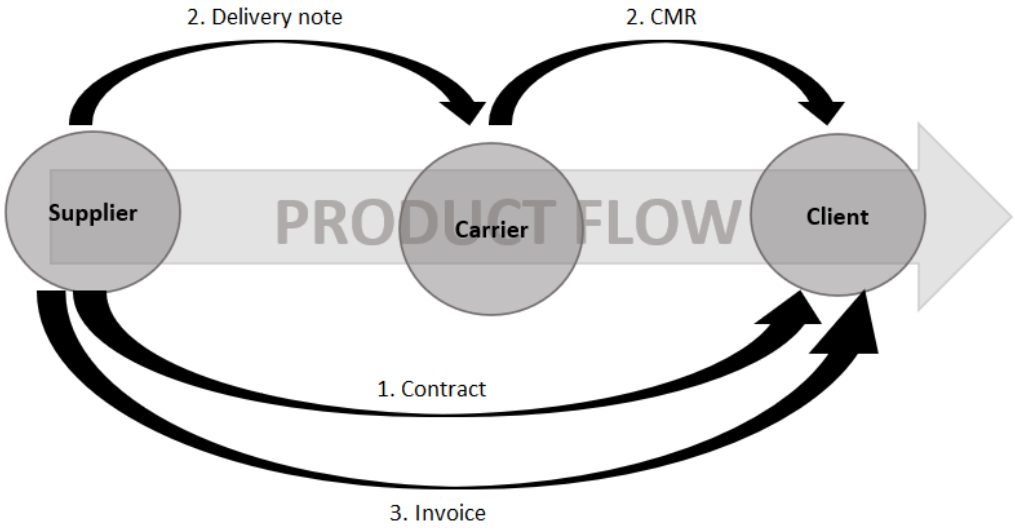


Figure 4: *Simplified information flows in food supply chain*

When two operators want to carry out a purchase/sale transaction, they establish a contract (1) in order to put on paper the conditions defined for the sale of goods. The contract is a very important document because it contains specific information about the product but also some logistics information. The contract includes for instance, the identification of the product, its price, the duration of the contract, the product specifications (linked to the technical data sheet which includes the composition of the purchased product), the date of delivery of the goods and the details concerning the transport of the goods (Union nationale des producteurs

de pommes de terre, n.d.). Contracts of this kind are drawn up and can be renewed for each purchase and sale operation between two companies.

As mentioned above, the terms and conditions for the transport of the goods are included in the sales contract. Before giving the merchandise to the carrier, the supplier ensures that the merchandise is provided with a delivery note (2). This document contains information about the goods purchased for the customer, so he can check whether the goods are as agreed. In addition, this document also serves as proof of delivery of the goods (IONOS, 2018). The customer also receives a transport document. According to the Convention on the contract for the Carriage of Merchandises by Road of 1956 (CMR), this document is filled by the carrier and is called a transport waybill (2). This document must be completed for every shipment of goods and is drawn up in accordance with the CMR Convention. This document contains: information on the sender, the receiver, the place of delivery, the delivery date, the place where the goods are picked up and information on the goods (weight, packaging, name, number of packages, etc.). Like the delivery note, this letter acts as a receipt. In addition to the waybill and the delivery note, the carrier must, of course, have the documents of the vehicle and the goods at his disposal.

The third document transferred from one operator to another is the invoice (3), which also has information concerning the product sold and especially the price. The invoice is linked to the contract as it is the official document that will result in the payment of the amount set out in the contract. The payment occurs if the terms of the contract are respected.

Chapter 2: Blockchain

In this chapter, we will deal with the blockchain in general by defining it, detailing its characteristics, its structure and the mechanisms making it operational. In order to describe this technology, the explanations are based on the Bitcoin and Ehtereum blockchain which are the most well-known blockchain. Next, we will focus on the smart contract, explanations will be based on the characteristics of the Ethereum blockchain, which is the reason why the understanding of the Ethereum blockchain will be important.

2.1 Definition of Blockchain

There are many definitions of blockchain in the literature, some more detailed than others, each containing interesting terms. For this reason, the combination of different definitions, provides an accurate one. Based on definitions from 'Blockchain France', the European Parliament and Scientific Articles, we define the blockchain technology as:

A digital data structure called a peer to peer distributed ledger, which store and transmit transaction in a securely and transparent way without central control body. It is a decentralized database, replicated and shared among the network's participants, containing a set of transactions whose validity can be verified by the participants (Blockchain France, n.d., Alharby & Van Moorsel, 2017).

Distributed ledger technology is defined by the European Parliament as a way of recording and sharing data across multiple data stores (also known as ledgers), which each have the exact same data records and are collectively maintained and controlled by a distributed network of computer servers, which are called nodes (Houben & Snyers, 2018).

2.2 The Rising Interest in Blockchain Technology

Blockchain technology was discovered with the introduction of Bitcoin cryptocurrency, created in 2008 by an unknown person or group named Satoshi Nakamoto (Swan, 2015). According to the Larousse dictionary, "*Bitcoin is a monetary unit of a virtual payment system allowing a community of users to exchange goods and services with each other over the Internet*" (Larousse, n.d). Mrs Swan (2015) in her book 'Blueprint for a new Economy', add to Larousse's definition the fact that Bitcoin are "*transacted in a decentralized trustless system using a public ledger called blockchain*". This cryptocurrency can be purchased in exchange for real money, goods or services or in the process of creating Bitcoin called 'mining'. Bitcoins are exchanged electronically through a virtual wallet on a computer, phone or web application (Nakamoto, 2008). Over the years after its creation, other blockchain have been developed. One

of them is the Ethereum blockchain, it was introduced in 2013 by Vitalik Buterin. This blockchain offered the same feature as the Bitcoin blockchain developed 5 years before but this platform was also able to build and run decentralized applications and smart contracts (Cruz & al., 2018). The success of the blockchain technology became so important that companies in the financial sector showed interest in it. Indeed, the decentralization of transactions executed on the Blockchain technology makes possible to record, confirm and transfer all kinds of financial assets (Swan, 2015). Subsequently, companies from all sectors became interested in the distributed nature of the blockchain. The most innovative companies discovered other features of this technology that could be a considerable advantage for their business. For instance, in Belgium and more specifically in Liège, a French student launched a website for the traceability of horses in the equestrian sector, this data storage system is based on blockchain technology.

2.3 Blockchain Architecture

In this chapter, we will detail the architecture of the blockchain technology. We decided to structure this chapter in two parts, the first one discusses the notion of ‘block’ in general, we detail the structure of a block header and a block body. The second one details the different participants of the blockchain, the notion of ‘node’ is explained.

2.3.1 Blocks

As the name suggests, a blockchain is a chain of blocks. The first block is called the genesis block. Blocks are added in the chain by nodes (nodes are defined in the next section) and each one contains a list of transactions. A block is composed of the block header and the block body where the transactions are stored. A representation of a block is shown in figure 5.

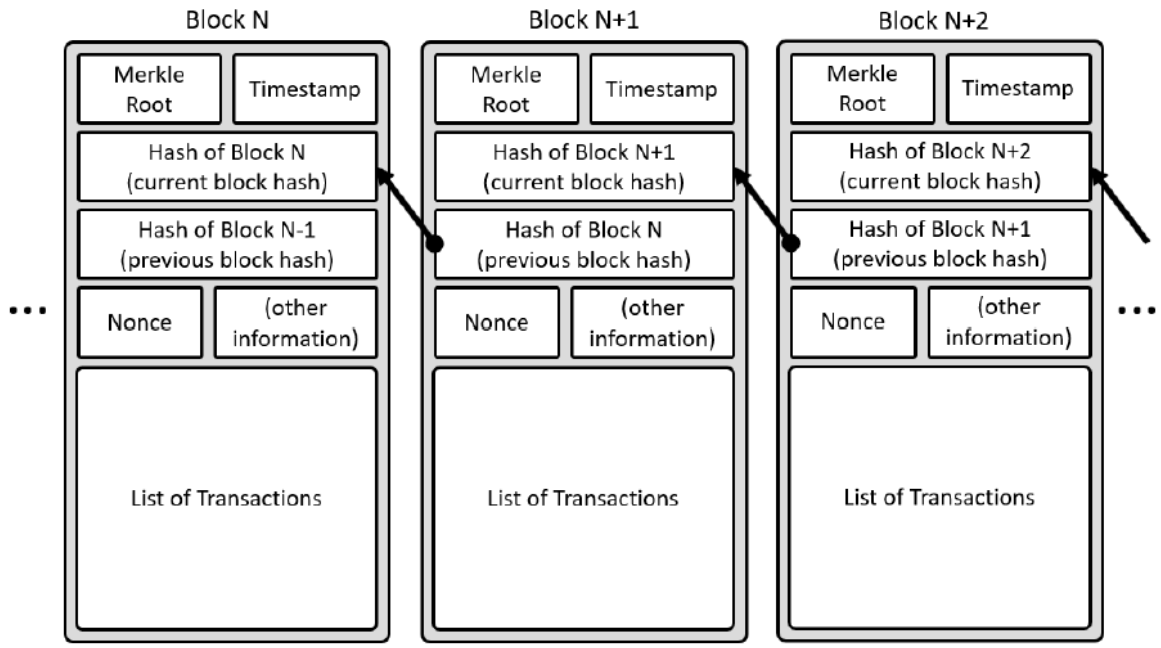


Figure 5: *Representation of a block (Reprinted from Chen & al., 2019, p.3)*

A block header can be defined as the identification of a specific block. It contains metadata, data used to characterize another data item (Larousse, n.d) about the block. Inside the block header we can find a Merkle root, the timestamp, the nonce, the previous block hash, the current block hash, a block version, the target, … (Zheng, & al., 2017). In order to make the following explanations clear, it is important to explain firstly what is a cryptographic hash function.

A cryptographic hash function is a mathematical function which can transform an input of arbitrary size to an output of fixed size (256-bit in this case). It is widely used in blockchain technology to store the data inside transactions. Indeed, it is interesting as it gives a unique identification of the transaction, it does not reveal its content and it gives a uniform length. Among the properties of this function, two are worth mentioning. Firstly, the hash function is collision-resistance, which means that it is computer expensive to find inputs which give the same output. Secondly, it is almost impossible to guess the input of the hash function based on a given output, this is called the hiding property (Itoo, 2019c).

Now let's detail the components of the block header.

The timestamp inside the block header gives the current time in seconds since a specific date, the block version indicates the set of block validation rules to follow. The block hash is

the result of the hashing function on all the components include inside the block header (Zheng & al., 2017). Some components of the block header deserve a deeper explanation.

The Merkle root inside the block header represents the hash value of all the transactions contained in the block body. Each transaction inside a block is represented by the hash of the transaction's data, it can be viewed as the identification number of the transaction. By hashing together pairs of transactions inside a block, we obtain a unique hash which is called the Merkle root. Thanks to the principle of the Merkle tree, it is possible to check the integrity of a transaction without knowing the hash of all the transactions but only some of them (Beck, 2018). The Merkle tree, which gives the Merkle root is illustrated in the figure 6.

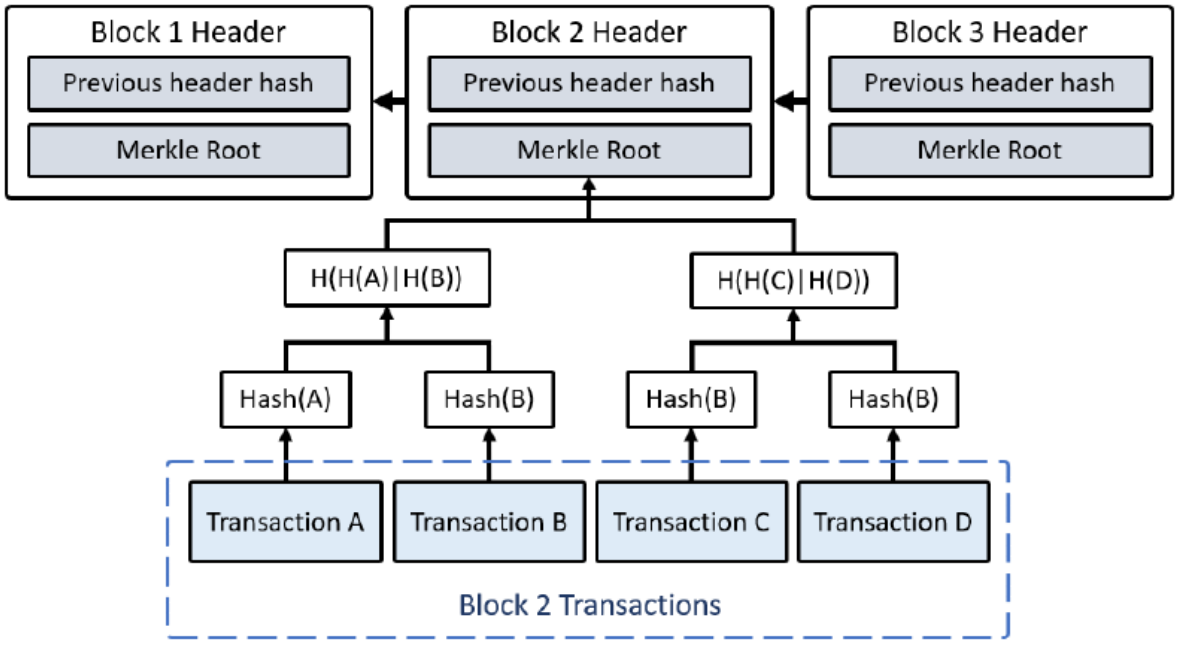


***Figure 6**: Illustration of a Merkle Tree (Reprinted from Chen & al., 2019, p.4)*

In the Bitcoin blockchain, the target is the threshold below which a block hash must be in order for the block to be valid and nBits is the encoded form of the target threshold. Therefore, when a miner (a node which computes blocks) wants to add a block to the blockchain, the hash of the block must be below the target value (the hash must start with a certain amount of 0's) (Bitcoin, n.d). To be able to reach a hash which is equal or under the target value, the miner can change the value of the nonce, also included in the block header. The nonce is therefore a number which increase for every hash calculation. Its value starts with 0 and is incremented for every hash calculation (Zheng & al., 2017). This procedure is computationally expensive and is specific to the consensus algorithm of the Bitcoin blockchain.

A representation of the content of a block header is shown in the figure 7 below. The block header can contain different data depending on the nature of the blockchain.

Block version	02000000
Parent Block Hash	b6ff0b1b1680a2862a30ca44d346d9e8 910d334beb48ca0c0000000000000000
Merkle Tree Root	9d10aa52ee949386ca9385695f04ede2 70dda20810decd12bc9b048aaab31471
Timestamp	24d95a54
nBits	30c31b18
Nonce	fe9f0864

Figure 7: *Representation of the content of a block header (Reprinted from Zheng & al., 2018, p.6)*

2.3.2 Participants

All the participants in the blockchain are called nodes. They are computers connected to the network and they can hold a copy or a part of the copy of the blockchain ledger (Swan, 2015). According to Adoni and al. (2019), two different kinds of nodes exist, it is called user node or validator node. The user nodes initiate transactions, they use the service provided by the blockchain technology. The role of the validator nodes is to validate the transaction initiated by the user nodes by reaching a consensus (the consensus algorithms are detailed in the section 2.4.2). The figure 8 illustrates the different kinds of nodes in a distributed system. The red nodes are the validator nodes, they hold the possibility to validate transactions.

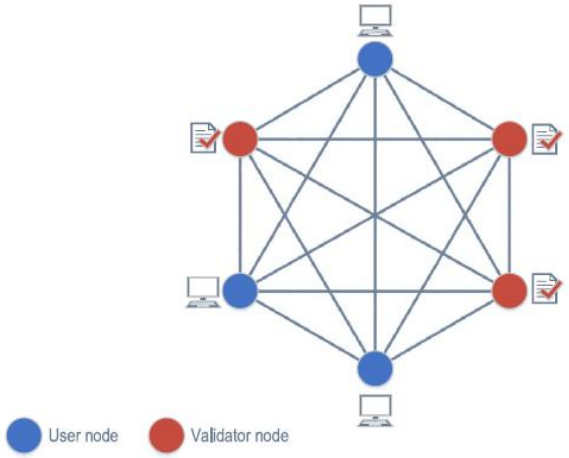


Figure 8: *Representation of the role of the nodes in the distributed network (Reprinted from Andoni & al., 2019, p.5)*

2.4 Blockchain Features

As it will be explained in the chapter 2.5, blockchain technology may have different properties depending on whether it is a public or private blockchain. In order to keep a guideline in this thesis, the characteristics presented in this section will be the ones we are interested in for the rest of the thesis.

2.4.1 Peer to Peer Distributed Ledger

The blockchain technology is defined as a distributed system. According to the university of computer sciences in Georgia, "*a distributed system is a piece of software that ensures that a collection of independent computers appears to its users as a single coherent system*". Bashir (2018) adds that in distributed systems, computers work with each other in a coordinated way to achieve a common goal. Besides being a distributed system, the blockchain is a peer-to-peer network. Indeed, the nodes of the blockchain, verify and record transactions, share their hardware resources (for instance, processing power and storage capacity) to provide the service offered by the technology (execute transactions between users) and services are accessible by other participants without intermediaries (Zeadally & Badra, 2015).

2.4.2 Consensus Algorithm

As mentioned above, the blockchain technology is a peer to peer distributed network, therefore there is no need of a central authority to control the integrity of nodes and data. Instead, a consensus is required between nodes. Therefore, when a node wants to create a block, specific work has to be done to prove the integrity of the created block. There are different approaches to reach a consensus in blockchain. The most common in public blockchain are Proof of Work and Proof of Stake. Proof of Authority is a rather common consensus algorithm for private blockchain. The POW approach is the one used in the Bitcoin blockchain although POS is used in the Ethereum blockchain. These approaches are used to choose which node is going to publish the next block and to describe the validation process of the block created. In the Bitcoin blockchain for instance, there is a lot of nodes working on the construction of the next block (as they are rewarded for the building of blocks) but only one node must be chosen and it must be an honest node (Zheng & al., 2017).

As mentioned before, to achieve consensus, a work has to be done by nodes and this work means in specific cases a lot of computer calculation, it is the case for Proof of Work. The computer calculation refers to the fact that nodes must calculate the hash value of the block header and this hash must be equal or smaller than a fixed value (the target defined in chapter

2.3.1). In order to achieve a smaller number, they change the nonce of the block. When a node reaches the target value, the block is broadcasted to other nodes to verify the correctness of the block. When the block is validated, the new block is added to the blockchain. In the decentralized network, valid blocks might be generated simultaneously when multiple nodes find the suitable nonce nearly at the same time, branches on the blockchain can therefore be created but it is unlikely that the same thing occurs for the following block. Thus, in the PoW approach, it is considered that the longest chain is the authentic one (Zheng & al., 2017). Unfortunately, as the POW approach demands a lot of computation calculation, there is a huge use of energy and therefore, a waste of resources.

The Proof of Stake approach is based on the ownership of currencies, it means that it is the node with more currencies, which will be chosen to generate the next block. On the one hand, this approach has a disadvantage as the selection is quite unfair, and one single person, the richest, could be dominant on the network. On the other hand, this alternative does not waste a lot of energy resources such as PoW (Zheng & al., 2017).

If PoW and PoS are widely used in public blockchain, Proof of Authority is used a lot in private blockchain. In this consensus algorithm, there are a specific number of nodes which are called the authority. These nodes manage transactions. This means that they handle the block creation process but in a different way as in other consensus algorithm. Indeed, there is a rotation system to distribute the responsibility of block creation among authorities, which means that each node which is defined as authority take turn in the block generation task. (De Angelis & al., 2018).

2.4.3 Security

Blockchain has several properties which ensure the security. Firstly, the distributed feature makes the blockchain secured as there is no single point of failure in the system (Radziwill, 2018). The fact that there is a consensus also ensures security as transactions must be validated before being stored and honest nodes will not validate incorrect transactions. Moreover, once transactions are recorded in a block, it is nearly impossible to delete them, they cannot be tampered, transactions are immutable (Choo & al., 2020). Indeed, if someone wants to modify one transaction, the hash of this transaction is going to change and the hash of the block too. It is going to lead to an invalid consensus algorithm and the following blocks are going to be invalid too as the block header contains the hash of the previous block. Moreover, anyone who wants to participate can use cryptography encryption, which is a technique to secure data inside transactions as it is going to be discussed in chapter 2.5.

Some attacks are still possible in some cases. These attacks can occur due to the vulnerability of the consensus algorithm, the loss of a private key by a participant or what is called the double spending attack (Li & al., 2017).

The attack due to consensus vulnerability can be achieved if one node or a set of nodes has the power to control the entire blockchain. If, for example, it is required within the blockchain that half of the nodes validate the block in order to be registered, and a group of nodes within the blockchain group together and reach the 50%, it is possible for them to attack the network. Attacking means altering the conformation of certain transactions, modifying their content, ... (Li & al., 2017).

Regarding private key, a security problem can occur if the key is shared or lost and a malicious participant uses it to record fraudulent transactions. This is why it is necessary to keep this key private and not to share it.

The last problem concerns the possibility for a participant to carry out the same transaction twice in order to make the first one void. When a transaction is made between two users, one of the users may generate a second transaction of the same type in a malicious approach before the validation of the first transaction. For example, User A and User B have agreed to record the terms of a contract within a blockchain. Between the time the transaction is initiated and the time it is confirmed there is a lapse of time (especially for PoW consensus). If operator A is malicious and has the ability to write within the blockchain, he can modify the conditions of the contract by initiating a new transaction which he will record in another block. Since the conditions are related to the same contract, only one of the two can be added to the blockchain. This is represented graphically by an intersection within the blockchain, which is divided into 2 chains. The first chain corresponds to the honest transaction and the second to the dishonest transaction. The next node adding a block to the chain should choose one of the two chains and this will allow the double spend attack to succeed or fail. The next node cannot know what the honest chain is. In principle, the correct chain is the longest (Itoo, 2019c).

2.5 Mechanism Behind Blockchain Transaction: Cryptography

In computer science, a cryptographic algorithm is a tool used to secure information. The information can be protected with functions that encrypt and decrypt data. In the case of blockchain, the cryptographic algorithm refers to a pair of keys. Every user of the blockchain owns one private key which is kept secret and one public key which is shared with other users (Itoo, 2019a).

2.5.1 Public and Private Key

As mentioned above, each user of the blockchain has a public and a private key generated when creating their account. These keys are linked together as the public key is calculated on the basis of the private key using a cryptographic algorithm (Itoo, 2019a).

These keys are used to secure sensitive data. For instance, when two participants want to exchange information, the information contained inside a transaction can be encrypted by the sender with the public key of the receiver and the receiver can only decrypt the transaction with its private key. It ensures that information cannot be read by someone else as the private key should be kept secret (Itoo, 2019a). An interesting use case of the private-public key combination within the blockchain is the digital signature.

2.5.2 Digital Signature

Like the hand signature, the digital signature is used to sign a document, a transaction. The digital signature proves that the document comes from the owner of the private key associated with the signature. This is used to authenticate the transmitted document. Authentication consists of two steps, signatures and verification. Of course, all the interest of these signatures is meaningful when the private key is kept secret (Itoo, 2019a).

Let's detail these two steps and take the example of two users who want to send each other a message through a blockchain. The sender of the message will proceed to the first step and sign the transaction with his private key. The signature corresponds to the combination of the private key and the hash of the message. In practice this means that the message will be hashed using a hash algorithm and then encrypted using the private key, the result of this process will give the digital signature. The digitally signed transaction is therefore transmitted within the network to another user. The second user, using the public key of the first user, can verify that the message has not been modified during its transmission and that the first user is indeed the author (Itoo, 2019a). The hash of the message should be the same as the hash obtained after the decryption of the digital signature with the public key.

An example of a digitally signed transaction approach is shown in the figure 9 below.

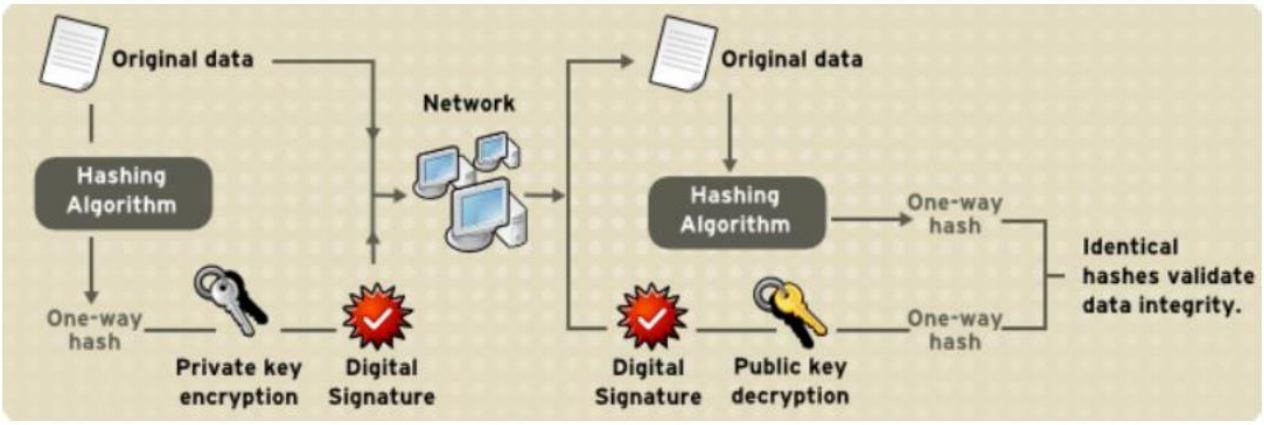


Figure 9: *Representation of a digitally signed transaction (Reprinted from Itoo, 2019a, p.5)*

2.6 Blockchain Taxonomy

As mentioned in chapter 2.4 'Blockchain features', the characteristics of a blockchain can be very different depending on its nature (private, consortium or public). Each different blockchain architecture defines the ownership of the data infrastructure.

The public blockchains are the most well-known. Indeed, these are the ones used in the exchange of cryptocurrencies such as Bitcoin or Ethereum that we have already mentioned several times. One specific feature of public blockchain is that transactions are visible by everyone and everyone can take part in the consensus process (Zheng & al., 2017). From this, results the fact that there is a very large number of nodes participating and therefore, the copy of the blockchain is stored on a large number of computers. Thus, it is difficult for a malicious node to modify information within the blockchain as it would mean modifying the information within all the copy of the blockchain stored on the computers of all the nodes. The less advantageous side of this type of blockchain is what is called the scalability problem. It refers to the fact that transaction rates are limited to avoid the congestion of the network and therefore the time to propagate a transaction within a block is longer (Zheng & al., 2017).

For consortium blockchain, the consensus process is limited to preselected nodes. The decentralization of the blockchain is not total as in public blockchain but only to a certain extent, there is not a huge number of nodes as in public blockchain. Therefore, consortium blockchain is a bit less secured because the technology is less decentralized than in public blockchain. But the efficiency is higher and the time needed to broadcast a transaction is lower (Zheng & al., 2017).

The last possibility for a blockchain is to be private. It means that the consensus protocol includes only the nodes from a specific organization. This characteristic can be associated with

a centralized network as the control over the verification and recording of transaction is owned only by one entity. Moreover, it means that this kind of blockchain can be easily tampered (Sato & Himura, 2018).

The blockchain ledger can also be permissioned or permissionless, which define the validation and the writing right of nodes. In permissionnless ledgers, the validation and the record of transaction can be made by any members of the network. In contrast, the nodes who can validate and record transactions are specific and predefined in permissioned ledgers. Four configurations are therefore possible if we consider public – private – permissionless and permissoned blockchain. This represents four different blockchain architectures depending on the use that is made. We include consortium blockchain with private blockchain in the 4 possibilities as the difference lies only on the dependency of nodes (independent nodes or one organization). The figure 10 below illustrates the 4 possibilities and their own features.

Blockchain Architecture	Permissionless	Permissioned
Public	- Anyone can join, read and write - Public server - Anonymous - Low scaleability	- Anyone can join and read - Only authorized and known participants can write - Medium scaleability
Private/ Consortium	- Only authorized participants can join, read and write - Private servers - High scaleability	- Only authorized participants can join and read - Only the network operator can write - Very high scaleability

Figure 10: *Blockchain taxonomy (Reprinted from Carson & al., 2008, p.5)*

The blockchain technology has been developed, its principles and characteristics were explained. We can move on to the section related to smart contracts.

2.7 Smart Contract

The smart contract concept was proposed by Nick Szabo at the end of the 20th century. The basic idea behind smart contracts was that many kinds of contractual clauses can be embedded in the hardware and software we deal with to make breaches of contract expensive for the breacher (Szabo, 1997).

With the development of blockchains and more particularly the Ethereum blockchain, we can define smart contract as an executable piece of code which runs on the blockchain to execute agreement between parties (Alharby, & Van Moorsel, 2017). The code includes conditions which, when they are met, execute the terms of the agreement automatically. One of the most well-known languages used to write smart contract is called Solidity (Alharby, & Van Moorsel, 2017). Smart contracts are computer codes, it means that they can read data from external sources and, under conditions, use them to execute the rules of the contract. As smart contract is built on blockchains, there are immutable which means that conditions cannot be modified once the contract is stored inside the blockchain (Itoo, 2019b). In order to be able to understand what is a smart contract, it seems essential to describe the Ethereum platform, which is, as bitcoin, a platform where users can exchange cryptocurrency. Indeed, Ethereum is one of the first blockchain which deployed smart contract.

2.7.1 Ethereum

In this section, we decided to focus on the Ethereum platform to detail Smart Contracts because it is one of the most popular platforms on which developers can create and execute smart contracts (Itoo, 2019b). At the core of Ethereum is the Ethereum Virtual Machine (EVM). According to a lecture about blockchain on the Coursera website, EVM is a virtual distributed computer that runs on every validator node in the Ethereum's network. EVM can be seen as the computer which runs the code on smart contract (Consensys Academy, n. d.).

Similarly to Bitcoin wallet, the Ethereum platform has accounts to store the state of ownership of ether (the cryptocurrency allocated to Ethereum), this kind of account is called an Externally Owned Account (EOA). Contrary to Bitcoin, Ethereum platform has another type of account which is the contracts account, they are used to execute smart contract transaction. In practice, it means that a created smart contract is identified by a unique address. When a transaction is intended to a smart contract address, the contract can be executed and send other transactions or even creates new contracts if the transaction met the conditions of the contract (Vujičić & al., 2018). Therefore, three types of transactions occur inside the Ethereum blockchain: a transaction between two externally owned accounts (to transmit data between two

users), a transaction which calls a contract (for instance, send a message to execute a function inside a smart contract) and a transaction which deploy a smart contract (create a contract account).

2.7.2 Structure

As stated before, a smart contract is a piece of computer code. It contains state variables, functions, function modifiers, events, struct and what is called enums (Prusty, 2017). When a transaction is intended to a contract account, functions are executed. Within this transaction, there are the parameters needed for the function to run correctly in the contract (Bahga, & Madisetti, 2016).

In a typical contract, we first find the keyword ‘contract’ stating that we will programme a smart contract. Then, the variables are declared, they can be of boolean type, integer type, a blockchain address, a string, a list, ... There is also what is called ‘struct’, which is a type used to group several variables. ‘Enum’ defines a common type for a group of values (Prusty, 2017). Next, events are defined and they are called within functions and stored on the blockchain (Prusty, 2017). Afterwards, the functions are declared. A specific function is called ‘modifier’ and is used to automatically check a prerequisite for the execution of a function (Prusty, 2017). Smart contract supports loops (if, else, while, for) as well as break (used to exit a loop) and return (Solidity, n.d). It is most of the time used inside function to define the condition of execution of the function. Finally, there is what we called the contract ‘constructor’ which initializes the variables and is triggered at each deployment of a contract (Prusty, 2017).

Now that we know how a smart contract is structured within its computer code, we can analyse how it is possible to interact with it. A basic approach to illustrate the interaction with a smart contract is to consider a transaction intended for the execution of a contract. The condition of the contract was previously declared and computed inside the blockchain by a validator node. The transaction has data within it that is used in the contract. If the conditions for the execution of the contract are met, the purpose of this transaction will be to carry out the event defined in the smart contract. In specific cases, the execution of the smart contract can call another smart contract. The representation of this interaction is shown in the figure 11 below.

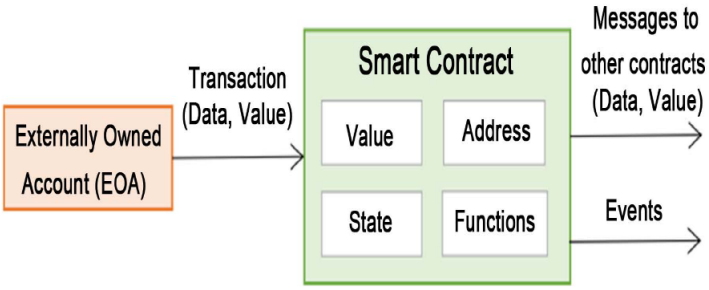


Figure 11: *Interaction with a smart contract (Reprinted from Mohanta & al., 2018, p.2)*

2.8 Summary of the Blockchain Framework

One approach to summarize all the information previously presented on the blockchain, would be to represent its framework in different layers. This representation is illustrated in the figure 12.

In a nutshell, five layers are depicted from the most specific to the most global. The first layer is the Data layer. It describes all the mechanism inside blockchain and the data inside transactions. The second one is the Network layer. It refers to the Peer to Peer network that is distributed. The Consensus layer is the third one and refers to the algorithm used in the blockchain by the nodes to enable one of them to build a block and other to confirm the validity of the block in order to add it to the chain. The second to last layer includes smart contracts that can be computed and implement in the blockchain. And the final layer refers to decentralized applications which can be developed on the blockchain structure (Wang & al., 2018).

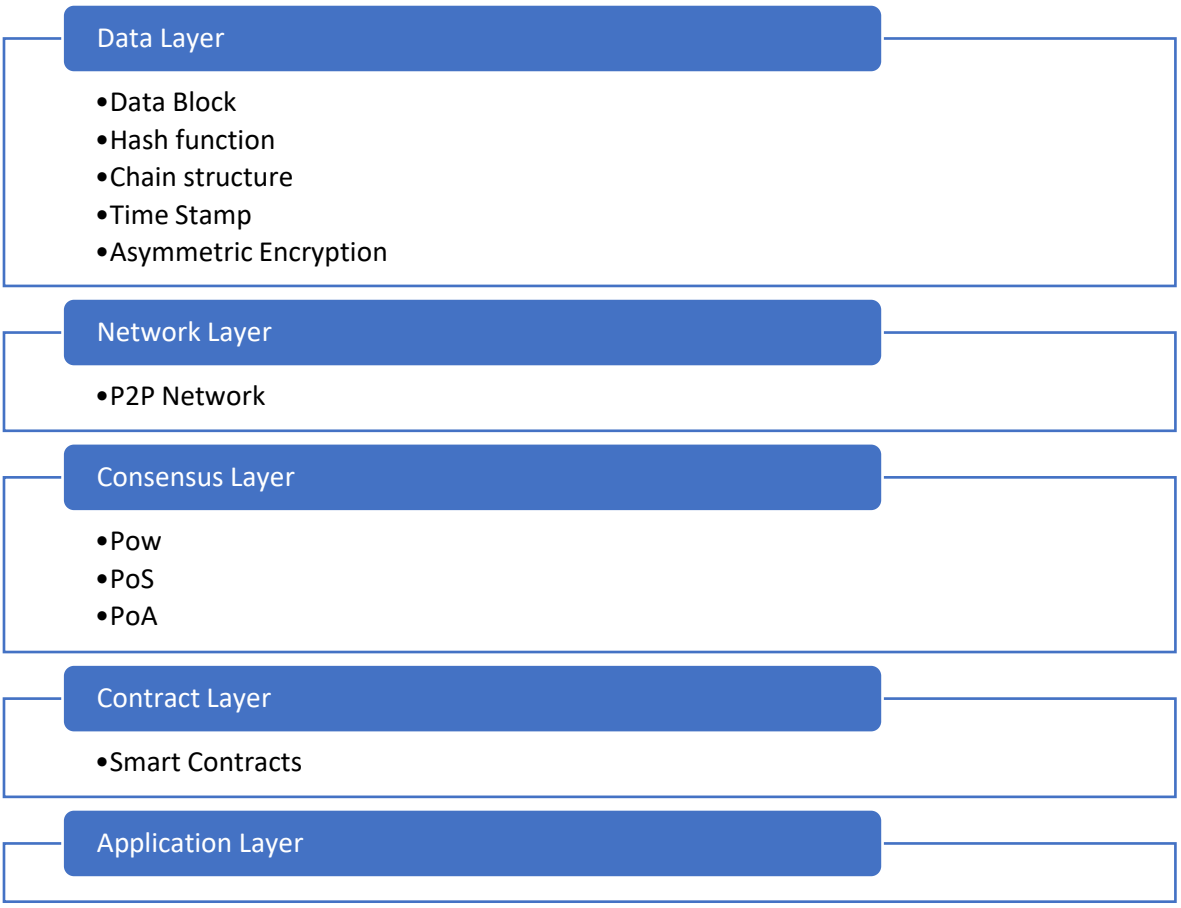


Figure 12: *Blockchain framework (Reprinted from Wang, & al., 2018, p.3)*

Chapter 3: Links between Food Supply Chain and Blockchain

Chapters 2 and 3 detailed the concepts of food supply chain and blockchain. As the objective of this paper is to analyse the challenges and opportunities of the use of this technology into a food supply chain, we will, in this chapter, detail the links between the characteristics of the blockchain and those of the supply chain. This will lead to an analysis of what blockchain technology can bring to supply chains in the food sector. Four important characteristics of food supply chains can be improved by blockchain technology and are detailed in this chapter. These four characteristics include: transparency of information, traceability of goods, collaboration between actors and data security. Let's detail these characteristics.

The various food safety and quality problems of recent years show a significant weakness and opacity in the communication of information by each operator. As a result, consumers are calling for greater transparency in the operations carried out within the supply chains (Fao, n.d). The Blockchain as a distributed ledger is used to record data. Due to the characteristics of the blockchain defined in section 2.4, we can certify that this ledger is secure and that once the information has been recorded, it is almost impossible to modify it. Therefore, if we consider for a given supply chain, that each actor would insert in the blockchain the information related to their productions (batch number, location, composition, ...), this information would be stored in transactions. These transactions, once validated, are located in the ledger and each node can have a copy of this ledger. Moreover, all the transactions recorded in the blockchain are difficult to tamper with. Therefore, it means that blockchain ledger provides a high transparency of data for the nodes in the network. We can imagine that these nodes are food safety control bodies, supply chain stakeholders and consumers. The blockchain can therefore respond to the need for more transparency in the data transmitted between operators within supply chains and also to the need for transparency requested by consumers.

As mentioned in Chapter 1.4.1, each actor operating in the food sector must ensure the traceability of its products. This means from a regulatory point of view ensuring the traceability of incoming products, of the transformations carried out within the company, and of outgoing products. In other words, each company must be aware of the origin of its purchases, internal transformations and the place where each product is sent and must be able to prove it. When a problem occurs, the traceability of each product provided by each company therefore makes it

possible to trace the path taken by the product. That said, since each stakeholder has only a small part of the information on a single finished product, it can be very costly in time and energy to trace a product completely (Yiannas, 2018). As explained in the first paragraph of this chapter, the blockchain as a distributed ledger would allow for each piece of information transmitted by an operator the record of the information within a block to be stored in a shared ledger. Since each block is time-stamped, the blockchain ledger would constitute a transaction history. A complete history of all the operations carried out within a supply chain available at a fixed location would make it much easier and quicker to consult the traceability of a product. Access to traceability information would be made available via a digital interface for each operator in the supply chain. This could be very useful in the case of a problem such as the contamination of a product. Indeed, the access to this history would make it possible to identify the source of the problem quickly and also how the product was distributed across customers (trace back and trace forward). The entire product manufactured should therefore not necessarily be recalled, but simply the contaminated batch. This could also provide the location of a product in 'real time'. Indeed, for example, when a carrier receives goods to be delivered, the information will be stored into the blockchain and this would mean that the manufacturer no longer has possession of the goods. When the carrier would deliver the goods and the customer would confirm receipt of the goods, this information is recorded in the blockchain ledger and it would be considered that the goods are now in the hands of the customer. Finally, a system for providing transparent data would also allow more efficient control.

Another food supply chain management need is collaboration. The transmission of critical data between different actors spread around the world can be difficult due to mistrust (Sara Saberi & al., 2019). Thanks to the approach by which blockchain is governed, i.e. by a consensus of nodes, blockchain could improve the collaboration between actors. Consensus allows the validator nodes in the network to check that each participant acts according to the rules defined in the blockchain protocol. The validation of blocks depends on compliance with the rules. In other words, from a practical point of view in the case of a supply chain, all the actors in the network would agree on the rules to be implemented within the network that would define the blockchain protocol. Validator nodes would work together to validate the blocks in order to check their integrity. As all operators would agree on the rules and that no one could violate the rules (the blockchain protocol defines the rules and it is not possible to do otherwise), this would improve co-operation and trust between the actors with regard to the transmission of information. Thanks to this process where everyone is aware of the approach to manage information, collaboration is ensured.

A last need identified for food supply chain is the data security. Indeed, in order to improve transparency, traceability and collaboration in food supply chain, the way information is shared must be secured (Abeyratne & Monfared, 2016). Moreover, the current problem is that this sensitive information is often stored on central computers. This means a centralized system where fraud and cybercrime can take place. As mentioned several times in this thesis, the blockchain is a distributed system which means that there is no single point of failure, it is not a centralized system. In addition, the transactions once recorded are immutable and therefore cannot be modified. Data security also helps to build trust among stakeholders.

Chapter 4: Model illustrating the Blockchain usage in the Food Supply Chain

As mentioned in the previous chapter, the inherent characteristics of the blockchain can improve data transparency, product traceability, collaboration between actors in food supply chains and data security. In this paper, we analyse its benefits as a tool for information sharing between stakeholders in a food supply chain. This information sharing globally includes information about each actor's production in order to ensure data transparency and traceability of goods, as well as information about operations between two actors, from the contract drafting to the payment of the invoice. The objective is also to allow a more sustained monitoring of food safety by the control bodies. The following sections discuss the decisions made regarding the characteristics and architecture of the blockchain in order to illustrate the usage of blockchain technology within a food supply chain.

4.1 Participants

A baseline scope must be defined regarding the number of operators in a supply chain integrated in the blockchain project. In the context of this thesis, the central participant will be the food manufacturer, all its suppliers as well as its customers will also be included in the model. The control bodies and the paying agencies are involved too at a certain extent.

- The manufacturer, suppliers and customers will have the ability to intend transactions that will be included in the blockchain and to read transactions. They are nodes and will have a copy of the ledger.
- The control bodies of each operator will also be members, but their involvement inside blockchain is limited to the digital signature of transactions to prove that the operator complies with food safety regulations. They will also have a very transparent reading power. Indeed, they will have access to almost all the information recorded within the blockchain ledger. As they are network participants, they are considered as nodes. However, we assume that they do not have a copy of the blockchain. Indeed, if the model develops, they should have a copy of the blockchain of every actor in different supply chains. It is not feasible in the long run.
- The paying agency will also be integrated into this model, its role will be to verify the available funds of the actors wishing to carry out a financial transaction through a smart contract and to execute this payment when the deadline occurs. In this project, its role is simply to say that the transaction can be intended as the fund are sufficient or not. In

this purpose, some intended transactions must be read. Therefore, they are participants to the network and are considered as nodes. For the same reason as the control bodies, they do not have a copy of the blockchain.

- End consumers will also be able to take advantage of the service provided by the technology but will not have any writing or validation power. They do not have a specific role inside the blockchain that could impact a transaction. They will not be a member of the network and therefore are not considered as nodes either.

The model assumes that the actors in the network know and trust each other, that the manufacturing company knows its suppliers as well as its customers, and therefore there is no need to impose anonymity on the participants. The fact that potentially competing suppliers or retailers may participate in the same network in a non-anonymous way can be a problem. However, we assume that market research can easily provide the identity of its competitors to any company that wishes it. On the other hand, disclosing information about a company's production, recipes or even prices to competitors can be dangerous. For this reason, regulated access to transactions in the blockchain ledger for each operator should be defined, this will be discussed in section 4.5.

4.2 Consortium Permissionned Blockchain

As presented in section 2.6, a blockchain can be public, consortium or private. For this thesis, the consortium blockchain is chosen. Indeed, in the constructed model, the blockchain is used as a tool for exchanging information between actors, this information can be sensitive and should therefore not be accessible publicly. Therefore, a public blockchain would be of zero interest in our case.

Then, when considering the other extreme, private blockchains, these have a consequent disadvantage mentioned in section 2.6, which is that they depend on a fixed organization and are therefore similar to centralized data storage. The blockchain therefore loses part of its secure character.

The consortium blockchain model meets the need of security with its decentralization and its private feature as only stakeholders in a supply chain are user nodes and can use the service offered by the blockchain. Therefore, it is the model chosen for the following chapters. The consortium blockchain will be ‘permissioned’ in order for a specific number of validator nodes to exist in the network to handle the recording and validation of blocks. It is not intended that user nodes should have block validation authority. Validator nodes are not operators of the

supply chain. By this we mean that they are service provider nodes, i.e. their purpose is to work for companies using the blockchain for various functions. In our case, for information sharing purposes.

So, we can imagine that the operators of a supply chain, wishing to implement blockchain technology to improve their information exchange, would get together to agree on the different things that will be allowed or not allowed within that system. The network operators (validator nodes) would apply the defined protocol and be the only ones who can write within the blockchain ledger. The supply chain operators will suggest transactions but only the network operators will be able to record them.

Some specific information in the consortium blockchain will be accessible to end consumers and therefore in a public approach, this will be discussed later.

4.3 Proof of Authority

The nature of the blockchain is determined, which allows us to focus on the choice of the consensus algorithm to be used. Among the consensus algorithms described in section 2.4.2, we have detailed the PoW, PoS and PoA algorithms.

PoW is the algorithm characterizing the Bitcoin blockchain. This public blockchain distributed over an impressive number of nodes must establish a competition between nodes for block construction. As the blockchain is public, the possibility of malicious nodes is considerable. An important computing power is thus necessary to be able to create a block, so it already eliminates a certain number of malicious nodes that would not have the patience to solve these mathematical problems as quickly as possible. In the case of a consortium blockchain, the validator nodes are limited. Therefore, forcing competition between nodes is not necessary.

Furthermore, it is not reasonable to give the power to build blocks to the node with the most financial resources (PoS).

Therefore, the choice of the PoA algorithm corresponds to the nature of the model with authoritative nodes to validate the blocks. The set of authoritative nodes dealing with transaction validation will be subject to a rotation system for choosing the one that will take care of the block registration as defined in chapter 2.4.2. These nodes validating and recording transactions within a block check, for example, that the transaction is not carried out several times for the same batch (especially in the case of smart contracts) by the seller or that a malicious node has not modified the information in its interest.

4.4 Verification

Each transaction carried out from one operator to another must be verified by both parties involved. There are two possible ways of ensuring this verification. Either the transaction is verified instantaneously or it is considered as pending while waiting to be verified. This verification depends on a set of rules determined by the network (Deloitte, 2016). The second solution is the most appropriate in the construction of our model. For instance, it is necessary for the receiver of the transaction to verify that the information included in the transaction is what he expects. Moreover, for contracts defined with payment event included, the paying agency must consent that payment is possible if the conditions are met. For this reason, the transaction will be put on standby until the verification takes place.

If we consider a time line, a member of the network wants to send information to another member of the network. The transaction is first put on standby for verification. When both members involved have verified the information contained in the transaction, the transaction is set as verified. A validator node is then chosen to record this transaction within a block. When the block is constructed it is broadcasted to other nodes which verify that the block and the transactions inside it are valid. After this, the block can finally be stored on the ledger. At this point, the information contained in the blockchain can be read by authorized members of the supply chain.

So far, the blockchain system in the model can be defined as a consortium blockchain with specific nodes independent of each other and independent from the supply chain stakeholders that validate and register each block. These nodes are subject to the Proof of Authority consensus algorithms so that the block is constructed by a different validator node each time and is verified by other nodes rather than just the node that constructed it. The supply chain operator are user nodes who intend transactions. We have also detailed in this section the verification principle of each transaction.

4.5 Access to the Information

An information access policy, i.e. a reading access, must be defined for each actor. Indeed, it is not necessary for a participant to have access to more information than necessary, as it is not imaginable that an operator could gain a competitive advantage as a result of the availability of information about another operator. Within the blockchain, these conditions must be defined. Three conditions are mandatory.

Firstly, the regulatory bodies have access to almost all the information available in the supply chain for the controlled operator excepting price information. The paying bodies only have access to transaction containing financial information for verification purposes.

Secondly, for those participants who can initiate or receive transactions within the blockchain, suppliers have access to the information they have written about their production and the contracts in which they are involved. Manufacturers have access to the information entered by their suppliers about their production, the information they themselves have written about their production and the contracts in which they are involved. Retail businesses shall have access to the information entered by suppliers of the purchased product and on the contracts in which they are involved. The carrier has access to very little information, as the characteristics of the product are not his concern. The information available to him is simply the information he receives on the delivery note (product name, weight, product identification, etc.) as well as the dates on which the carrier receives the goods and the delivery location. The supply chain stakeholders also have access to specific information such as the new identification number of the product sold. It will be detailed further.

As a result, each member intends to register his information within a transaction in the blockchain and this information is only visible to the participants who have the access. The accessibility of the information is defined in the protocol of the blockchain. In addition, it is also possible to provide access to parts of the information included in a transaction. The participant who records information can encrypt parts of the transaction using a public key and the user for whom the encrypted data is intended can decrypt the information using the corresponding private key. For example, for regulatory bodies, access to all recorded information will be allowed in order to ensure data transparency and allow optimum traceability, except for price information contained in purchase and sale contracts. Indeed, there is no regulation requiring the dissemination of these details. We can consider that price information is encrypted.

As the final consumer will also be entitled to take advantage of this service, specific basic information will be provided to him. Therefore, there is no point in hiding this information from operators. Indeed, they can access it when they are consumers.

4.6 Model

In this section, we present an innovative model representing the use of blockchain in a simple supply chain. This model will contribute to answering our research question. It will illustrate the way in which the blockchain can be used to improve the exchange of information between the different actors in a food supply chain. Thanks to this model, we will then study the challenges and opportunities of the use of the blockchain in the food industry.

The construction of this model is based on extensive research on the food industry sector in general and the food supply chains. We have identified five characteristics of food supply chains. These include food safety, food quality, food labels, traceability and product diversity. In-depth research was carried out on the regulations applicable in this sector and interviews were conducted with members of the SPF Economie and the Afsca for general regulations as well as with members of Certisys and Biowallonie for the organic regulations. Interviews were also conducted with three manufacturing companies active in this sector. The detail on these interviews can be found in appendix f. This enabled us to establish the main information flows between the players that will form the basis for the development of our model.

We also made numerous research regarding the blockchain infrastructure. As a result, we were able to detail the links between the blockchain and the food supply chain. It also allowed us to determine the characteristics of the blockchain protocol. A permissioned consortium blockchain whose governance is done through the PoA consensus algorithm between independent nodes offering their service for blockchain applications.

Figure 13 below illustrates the use of blockchain in a simple food supply chain. The model represents the food supply chain on the left of the figure with the stakeholders and the different flows between them. A user interface is represented on the middle. It can be represented as a web page where operators are able to initiate transactions. The blockchain infrastructure is illustrated on the right.

For the consistency throughout this thesis, we define actors as set out in Section 1.1 and information flows as detailed in Section 1.7. We consider 4 types of operators within the supply chain: producers (farmers), manufacturers, carriers and retailers. All of them are represented on a yellow background. A carrier is represented between the manufacturer and the distributor. There may also be one between the farmer and the manufacturer. But we do not consider it within the scope of our model, which is why it is shown as a dotted line in the figure 13. Supply chain operators are also nodes and more specifically user nodes (UNode) they are illustrated on

the blockchain side in the model such as the service provider nodes (Vnode), these are shown on a grey background.

There are three types of flows between supply chain stakeholders:

- Goods flows (light blue arrows). These include raw materials and finished products. The flows of semi-finished products are not illustrated, but they may be present between different manufacturers.
- The financial flows (dark blue arrows). The financial flows are made through the intermediary of a paying agency specific to each operator.
- The information flows (orange arrows). Among them we specifically consider the purchase and sale contracts between the operators, the invoice linked to the flows of goods and the delivery note upon receipt of the goods as documents containing the useful information for each operator.

The purple arrows represent the interaction between the blockchain and the supply chain. The black arrows represent the actions carried out within the blockchain.

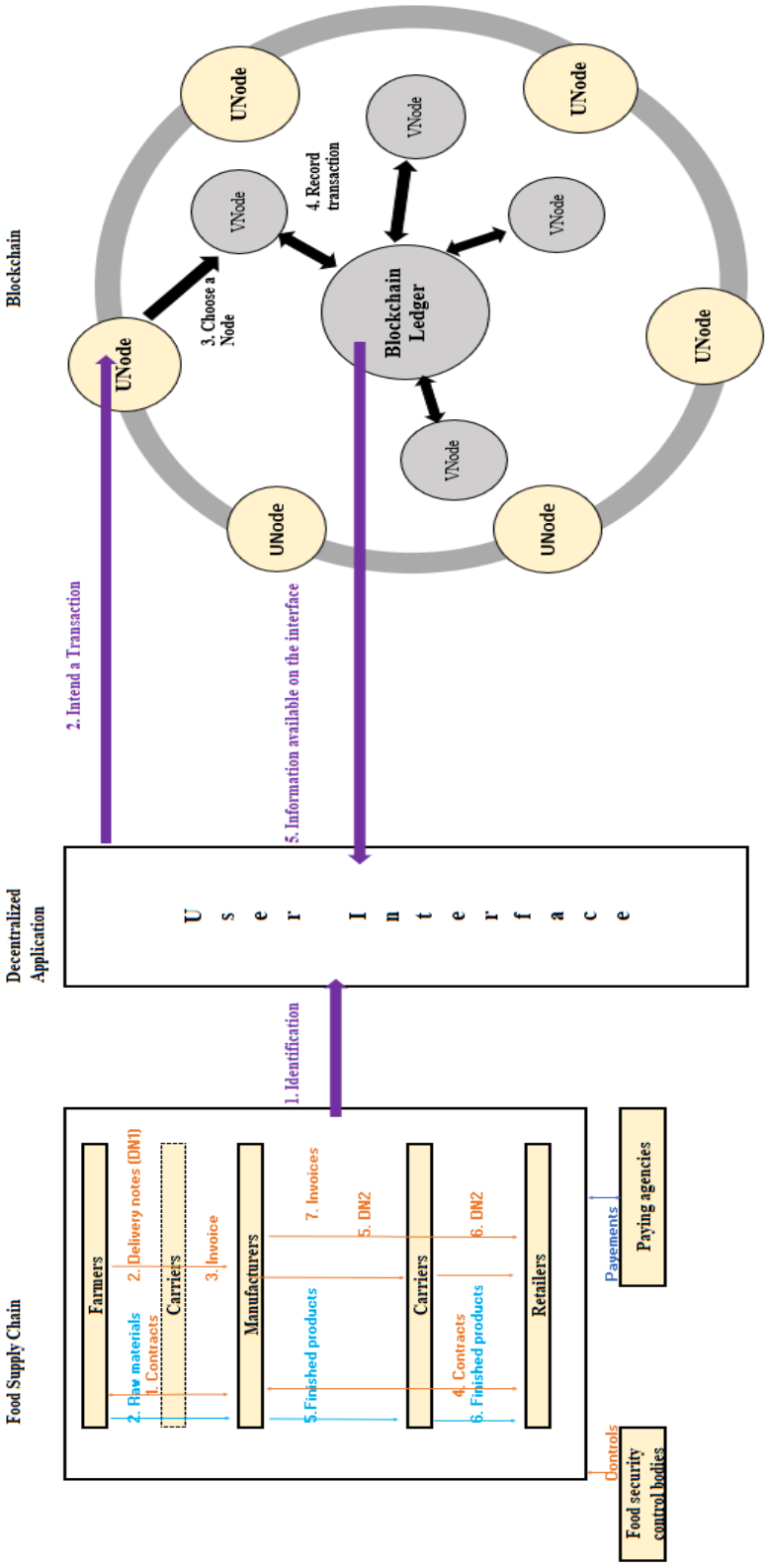


Figure 13: *Illustration model of the blockchain usage in the food supply chain*

Let's focus on each frame. The food supply chain side, the user interface side and the blockchain side.

The food supply chain side is shown in Figure 14 below. The operators and the different flows are shown. The details of these operators and flows are mentioned above. The flows have been numbered in the chronological order in which they are carried out. Let's explain it briefly.

The farmer and the manufacturer establish contract on which they fix the sales conditions and the delivery conditions of the products (1. Contract). Then, the merchandise (2. Raw materials) is delivered to the manufacturer with the delivery note (2. Delivery note). If everything corresponds to what was written in the contract, the manufacturer accepts the merchandise and pays the invoice (3. Invoice). The same operations are carried out between the manufacturer and the retailer. Excepting that we consider the transport is handled by specific carrier. Therefore, the delivery note (5.DN2 and 6. DN2) is transmitted by the manufacturers to the retailers by the intermediary of the carriers. The food security control bodies control every operator in the supply chain (each sector of activity having a specific control frequency) and the paying agencies carry out all the financial transactions on a regular basis.

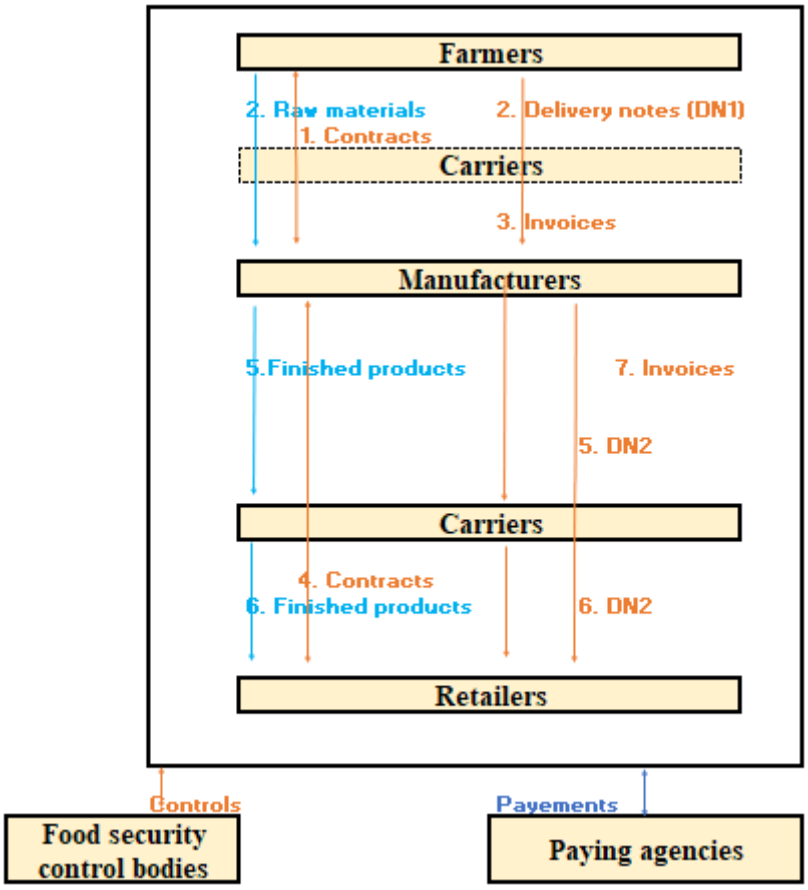


Figure 14: *Food supply chain representation reprinted from the model.*

Let's take a closer look at the centre window in the model which is the user interface. The blockchain is a system that contains a ledger in which the information is going to be stored. The information stored in the ledger includes all the verified transactions carried out within the supply chain. A user interface must be defined to initiate transactions. Indeed, we assume supply chain stakeholders do not have IT skills and cannot write by themselves inside the blockchain.

The model illustrates a user interface where each operator can enter the information relating to its transactions. One can imagine the recording of information by filling in forms inside a web page. In order to access the platform, each operator will have to log in with a nickname corresponding to their public key (their address on the blockchain) and a password corresponding to their private key **(Figure 13: 1. Identification - purple arrow)**. Each operator must register the information related to the products he has purchased (supplier, weight, origin, identification number, ...) which corresponds to the registration of incoming products. The products he manufactures (list of ingredients, origin, identification, ...) which corresponds to the internal traceability. And the products he sells (customer, weight, origin, identification, ...) which corresponds to the registration of outgoing products. As well as useful information about the company (identification, origin, ...). The rules governing contracts between operators are also recorded (delivery date, transport operators, weight, identification, etc.). The information entered must be in accordance with what is legally required to be transmitted to the control authorities. Figure 15 shows an example of information to be inserted by each operator within the interface. Each line (from T1 to T8) represents a summary list of these information. These lines will correspond to transactions within blocks.

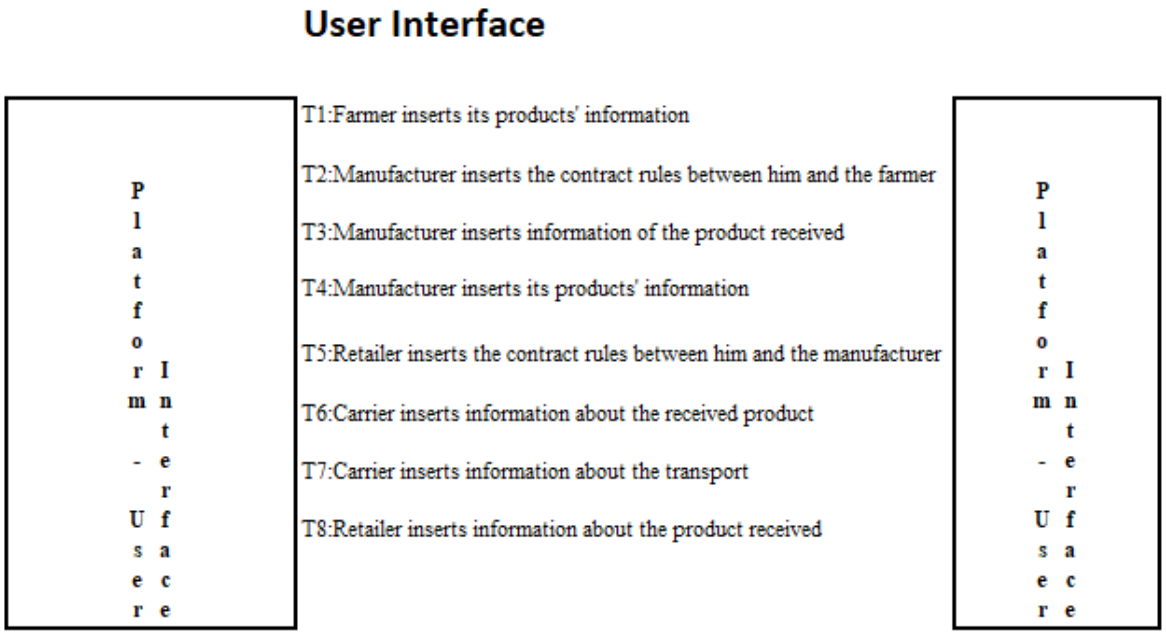


Figure 15: *User interface representation in the model*

All these records can be used to complete profiles. Profiles are tables on the user interface which contain the information recorded on the blockchain. This makes it possible to read the information in a clear and summarized form. There are product profiles, operator profiles and transaction profiles within the platform. These profiles are structured like tables. These tables can be associated with relational databases, i.e. the transaction table contains information from the operator table as well as from the product table, it is a consolidation of information from the operator profile, product profile and smart contracts. The transaction table is therefore really important as it consists of a lot of consolidated information. The product profile is illustrated below in figure 16 and the operator profile in figure 17. Let's briefly detail their contents.

The product profile shown in figure 16 includes the company identification (IDC30), i.e. each company must register its suppliers using the company number, the product name (Product30), the product identification (for example, its batch number, id30), the list of ingredients (the list of product components with the weight in percent, i1 and i2), the total weight of the product, the organic character of the product as well as the supplier of the ingredients and their reception date.

We can imagine that the identification of the company mentioned in the first column can be linked to the profile of the operator. Therefore, when an operator with access to this product profile clicks on the identification number of the company, he is directed to the operator's profile.

Product profile							
Identification of the company	**Name**	**Identification number**	**Ingredient list**		**Weight**	**Organic**	**Supplier and reception date**
IDC30	Product30	id30	i2	(100-x)%	kg	Yes/No	IDC20
			i1	x%			D20

Figure 16: *Product profile*

The operator profile is illustrated in figure 17 for an operator whose sector of activity is manufacturing (M3). In this profile, the name of the company is indicated as well as the company number (identification) as in the product profile. The operator profile also includes the address and country where the company is located. It is also indicated whether the company has been controlled by an inspection body and in some cases by the organic certification body.

The profiles of the operators are only visible by their customers as well as by the control bodies. Therefore, when an operator is controlled, the control body digitally signs the profile of the actor concerned so that these customers can see that he has been controlled and thus, his products too. It means that he complies with the regulations applicable in his sector of activity. This is equivalent for any certification body that should also control this operator, such as the organic certification body considered in this model.

Operator Profile						
Activity	**Name**	**Identification**	**Address**	**Country of origin**	**Control**	**Organic**
M3	N30	IDC30	A30	C30	Yes/No	Yes/No

Figure 17: *Operator profile*

The general representation of the transaction profile for a specific finished product is shown in Figure 18 below. The transaction profiles will be fully visible by regulators (prices of goods will not be disclosed within these profiles) and partially visible by operators depending on their access. This table will be also partially visible to end consumers but not on the user platform depicted on figure 13. In the figure 18, the light green columns represent the information available both privately (within the food supply chain network) and publicly

(information available to end customers). It is the retailer that will give access to this information to consumer. We can imagine that it will be an internet page accessible with a QR code containing the light green columns.

Each row represents the consolidation of information from one or several transactions. In this table we find the activity of the company, its identification, its origin (location), if the company has been controlled or not and the organic feature of the operator for this product. All of these data come from the operator profile. We also find the name of the product, its identification, its list of ingredients and weight as well as its organic feature or not which came from the product profile. The state of the product (R: raw material, SF: semi-finished, FP: finished product), its date of receipt, its delivery date, the supplier and the customer linked to the product are also mentioned. This information comes from the smart contract established between the actors.

Transaction Profile

Activity	Identification number of the company	Product Name	State	Product ID	Origin	Ingredient List (% and kg)	Weight	Reception date and Sender (FROM)	Delivery date and Receiver (TO)	Access	Control	Organic
R	IDC50	P30	FP	id30	C30	L7	KG	D93 from IDC30, IDC40		R,A	Yes/No	Yes/No
C	IDC40	P30	FP	id30	C30	L7		D92 from IDC30	D800 to IDC50	C,R,A		
M3	IDC30	P30	FP	id30	C30	L7		D90 from IDC20 D81 from IDC21	D700 to IDC50	M3,R,A		
M2	IDC21	P21	SF	id21	C21	L6		D70 from IDC12 D80 from IDC13	D600 to IDC30	M2,M3,A		
M1	IDC20	P20	SF	id20	C20	L5		D50 from IDC10 D60 from IDC11	D500 to IDC30	M1,M3,A		
F8	IDC13	P13	R	id13	C13	L4		D40 from IDC8	D400 to IDC21	F8,M2,A		
F7	IDC12	P12	R	id12	C12	L3		D30 from IDC7	D300 to IDC21	F7,M2,A		
F6	IDC11	P11	R	id11	C11	L2		D20 from IDC6	D200 to IDC20	F6,M1,A		
F5	IDC10	P10	R	id10	C10	L1		D10 from IDC5	D100 to IDC20	F5,M1,A		

Figure 18: *Transaction table*

In Figure 18, we consider four raw materials (‘R’ in the third column), two semi-finished (SF) products and one finished product (FP). Each line represents the insertion of data by each operator and this is how the table is defined, one line per operator. Several suppliers as well as several manufacturers are represented in order to illustrate the accessibility of information.

For example, operator IDC10, a farmer, inserts its activity (primary producer, F5), its identification number (IDC10), the name of his product (P10), the state of the product (R), the identification of the product (batch numbers or other indications allowing to identify it, id10), the list of ingredients composing it (weight and percentages are indicated as on a technical data sheet, L1), the total weight of the batch he is going to sell, the date of the reception of each ingredient composing his product and his supplier (reception date: D10, supplier: IDC5). Afterwards, he will also insert the delivery date of his production as well as the identification of his customer (delivery date: D100, customer: IDC20). The general access to the information by the other operators is defined within the blockchain, it is represented in column 13 called ‘Access’ (‘A’ means control bodies). The ‘control’ and the ‘organic’ column can take the value ‘yes’ or ‘no’ depending on if the operator has been controlled or not. The organic character of a product can be automatically defined thanks to smart contracts. We will detail this point in the next section. As mentioned, the inspection body has access to the total information of the transaction profile, this transparency allows a better food safety as well as a total access to the traceability of the product.

Figure 19 illustrates how the transaction profile is visible for the farmer. In Figure 19 we can see that the farmer, in this case IDC10, has access through the transaction profile: to the publicly visible information (the light green cells) to the information he has recorded, i.e. the line within the table that contains his data (the yellow line) but also some specific information relating to the sale-purchase contract that has been made between him and the manufacturer (the date of delivery of the goods for instance) as well as the identification of processed products in which his production can be found (the dark green cells).

Transaction Profile												
Activity	**Identification number of the company**	**Product Name**	**State**	**Product ID**	**Origin**	**Ingredient List (% and kg)**	**Weight**	**Reception date and Sender (FROM)**	**Delivery date and Receiver (TO)**	**Access**	**Control**	**Organic**
R		P30	FP	id30	C30					R,A	Yes/No	Yes/No
C		P30	FP		C30					C,R,A		
M3		P30	FP	id30	C30					M3,R,A		
M2		P21	SF		C21					M2,M3,A		
M1	IDC20	P20	SF	id20	C20			D50 From IDC10		M1,M3,A		
F8		P13	R		C13					F8,M2,A		
F7		P12	R		C12					F7,M2,A		
F6		P11	R		C11					F6,M1,A		
F5	IDC10	P10	R	id10	C10	L1	KG	D10 from IDC5	D100 to IDC20	F5,M1,A		

Figure 19: *Representation of the transaction profile for the farmer*

The way transaction profile is perceived by the manufacturer as well as by the retailer is illustrated in appendix d.

The last section of the model to be analysed is the part on the right related to the blockchain infrastructure. This part is shown in Figure 20. Each piece of information entered on the user platform initiates a transaction if it corresponds to the rules defined in the blockchain protocol **(Figure 13: 2. Intend a transaction - purple arrow)**. Between the intention to record a transaction and its registration, the transaction is verified by the relevant actors of the supply chain within the user platform.

Let's look at Figure 20 in detail. When the transaction is initiated and verified, it is 'sent' to the user node corresponding to the operator who initiated the transaction (a UNode shown on a yellow background in Figure 20). This node holds a copy of the blockchain. However, it does not have writing access within a block. This is represented in figure 20 by the fact that these nodes are at the border between the outside environment and what happens inside the blockchain. Therefore, this user node will transmit its transaction to a validator node **(Figure 13 and 20: 3. Choose a Node - black arrow)**. This node will be chosen arbitrarily according to the protocol of the PoA consensus algorithm (rotation system for the choice of the validator nodes that create the blocks). This chosen Validator Node will record the transaction within a block. To do this, it needs to consult the ledger in order to have the hash of the previous block. As a reminder, the hash of the previous block must be contained in the following block header. This is why the link between VNode and Blockchain Ledger is a double arrow. When the block

is created it is broadcasted to all the nodes for the validation of the block. When the block is validated, it is stored in the blockchain ledger **(Figure 13 and 20: 4. Record transaction - black arrows)**. Once internal blockchain operations are done, the transaction becomes visible within the platform **(Figure 13 and 20: 5. Information available on the interface - purple arrow)** in the form of tables as shown in figure 18.

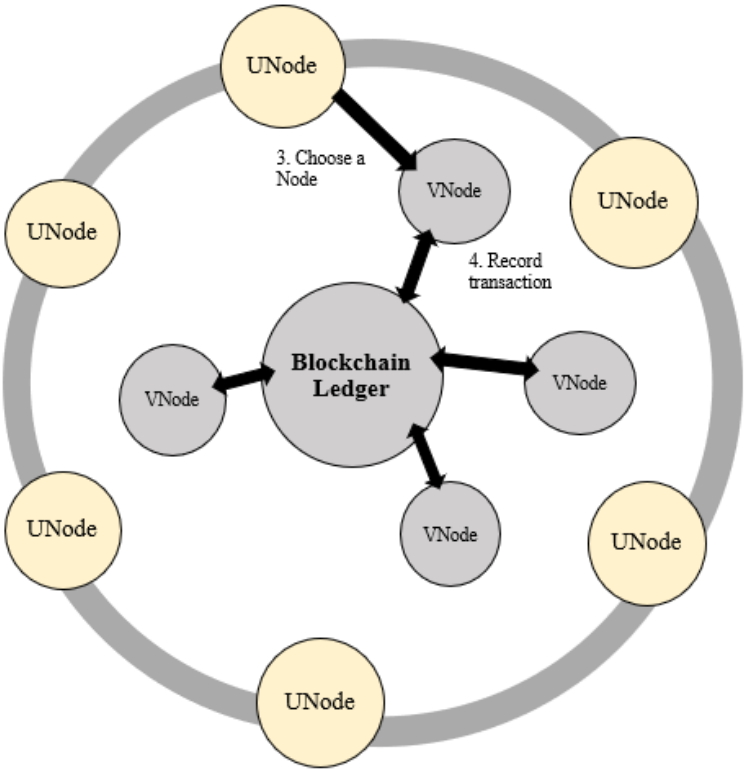
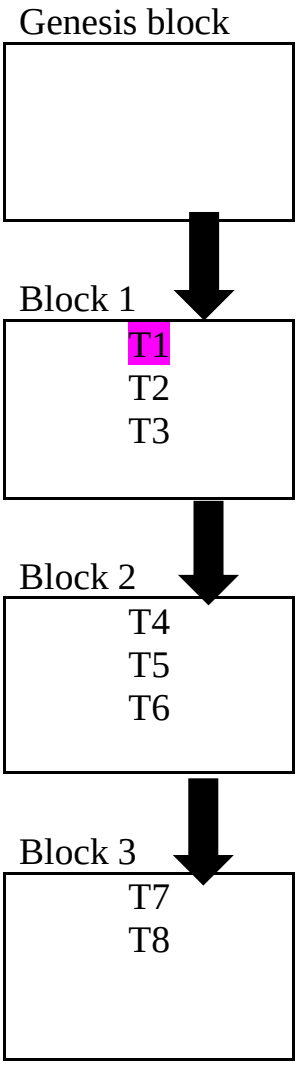


Figure 20: *Blockchain representation in the model*

Each transaction intended to inform an operator is recorded within the blockchain as a transaction containing the identity of the issuer of the transaction, the identity of the receiver (their public addresses), and the hash of the information transmitted. When two operators carry out a buy/sell operation and record the terms and conditions of sale on the platform, these same terms and conditions are written into a smart contract in the form of a computer code and this contract corresponds to a transaction on the blockchain ledger. This contract will be executed automatically if the conditions are respected. The execution will result in the payment of the invoice by the paying organization. A simplified representation of the blocks containing the transactions represented in Figure 15 as well as the representation of a transaction are shown in Figure 21 below.



T1	
Address of the sender	0x742d35cc6634c0532925a3b844bc454e4438f44f
Address of the receiver	0xdg76cd25977e0a5ae17155770273ad58648900d3 0x53d284357ec70ce289d6d64134dfac8e511d8a3d
Hash of the transaction	b4fce0c41eca4e44080ecdce0769910c133bec192a 6739c65f9fcaf8fbc77756

Figure 21: *Blocks representation in the model*

4.7 Interpretation for a General Food Supply Chain: case of tomato sauce

This chapter extends the model defined above to specific products and actors. For the sake of clarity, we will consider as product tomato sauce because it is composed of few ingredients and therefore the number of operators may be limited. The different operators are: a farmer – the tomato producer –, a manufacturer – the tomato sauce manufacturer –, a transporter – carrying out the transport of tomato sauces from the manufacturer to the retailer – , the retailer, the Afsca as control body (we consider only one control body in this example) and a bank (we consider only one paying agency also for all the actors).

The flow of goods includes the transfer of tomatoes from the farmer to the manufacturer as well as the transport of tomato sauces from the manufacturer to the retailer by the transporter.

The information flows include the contracts established between each operator (the contracts for the purchase and sale of goods), delivery notes and invoices; these documents form the basis of the information to be recorded in the platform. The contract includes the conditions of the sales agreement between two parties as well as the information that must be provided in order for the buyer to comply with the regulations: for example, the transmission of the information present on the product's technical data sheet (detailing the composition of the product in percentages and weight). This sheet is very important for the manufacturer, so that he can draw up the list of the ingredients constituting his finished products on the basis of the ingredients making up the raw materials purchased. For example, if the manufacturer buys a basil paste to incorporate into his finished product, he must have the information concerning the ingredients of this paste so that he can have a correct list of ingredients on his finished product.

The financial flows correspond to the payments made by the payment agency on the manufacturer's behalf to the farmer and the transporter as well as on the retailer's behalf to the manufacturer. These are made during the automatic execution of a sale smart contract.

The figure 22 below illustrates an example of information that could be entered into the platform in the case of tomato sauce products. When the tomato producer harvests his production, he enters the details of his products on the platform and shares them with the manufacturer. This figure represents the information that could be included in the product profile of this specific batch of tomatoes and in the transaction profile of the tomato sauce produced with this batch of tomatoes.

Tomatoes	
Identification de l'exploitation agricole :	BE0864964810
Name :	Tomatoes
Identification (production date, expiry date or batch number) :	Produced the 16/07/20
Ingredient list : inputs :	Fertilizer: Bone powder (3kg)
Weight	100 kg
Fournisseur :	Company located in the Netherlands
Reception date :	01/06/20
Organic	Yes

Figure 22: *Example of a transaction performed within the user interface*

The transaction will be on standby until it is verified by the farmer and the manufacturer. When it is verified, this transaction will include the farmer's address and the manufacturer's address as well as the hash of the transaction within the block as shown in Figure 21. The information in Figure 22 will therefore be included in one transaction. This will be translated into a product profile and will also complete the first line from the bottom of the transaction profile.

Then, they agree on the conditions of the sale and one of the participants in the contract insert into the user platform information about the goods to be sold, the delivery date, the weight and any other necessary information. Below in the figure 23 an example of the information recorded on the interface user that intends to create a sale smart contract between the tomato producer and the tomato sauce manufacturer is illustrated.

Tomato sales contract between farmer and manufacturer	
Identification of companies :	BE0864964810
	BE9589530901
Product :	Tomatoes
Weight :	100 KG
Product identification :	Produced the 16/07/20
Adresses :	From Liège To Brussels
Price :	100 euros
Delivery date :	27/07/20

Figure 23: *Example of recording information contained in a sales contract*

This information is again on standby until its verification. Then, it is transmitted to a validator node that will code a smart contract. Under this model, the buy-sell smart contract is illustrated by three events. The success event, the payment event and the failure event. If the goods are received by the manufacturer in the defined quantity, defined delivery location and on the defined delivery date, the success event occurs and the payment event also occurs. Otherwise, the failure event occurs and payment will not be made.

When the smart contract is stored on the blockchain ledger, the transaction profile is filled in with information contained into this smart contract (such as the expected delivery date). Later, when the buyer receives the batch, the smart contract is executed and the transaction

profile is automatically filled with data such as the reception date (that could be different from the delivery date if an accepted lead time was mentioned in the smart contract).

4.8 Interpretation for an Organic Food Supply Chain

4.8.1 Calculation of Organic Production Conditions

An interesting application of the blockchain in the food supply chain is the case of organic food. Indeed, as explained in chapter 1.3.2 dedicated to the organic label, the European rules for determining whether a food is organic are very accurate. Within a blockchain, these determining conditions can be computed within a smart contract. As a result, a food product can automatically be defined as organic or not depending on the list of ingredients and their percentages available on technical data sheet. As a reminder, the rules to be respected in the composition of an organic food are:

- At least 51% of the ingredients by weight are agricultural (without considering water and salt)
- At least 95% of the agricultural ingredients by weight are organic

In order to apply these conditions, it must first be defined which ingredient is agricultural ingredients and then which agricultural ingredients are organic. Let's detail these conditions mathematically.

Index :

i= ingredients (raw material) in the finished product

Parameters:

a_i = takes the value 1 if the ingredient is agricultural

0 if it is not

b_i = takes the value 1 if the ingredient is agricultural and organic

0 if not

p_i = proportion of the ingredient in the product (expressed as a percentage of the total weight)

w = the sum of the proportions (expressed as a percentage by weight) of each raw material in the finished product excluding water and salt. Water and salt are not included in the calculation of the agricultural percentage. Each formula defined for each condition will have to include the division by ‘w’ in order not to consider the totality of the product but the totality without water and salt.

Condition 1 : If, for all ingredients (raw material), the sum of the proportions of the agricultural ingredients is greater than or equal to 51% by value, condition 1 is met. The value of ‘A’ must be greater than 51%.

$$A = \sum_{i=1}^{n} \frac{(a_i * p_i)}{w}$$

Otherwise the product is not organic.

Condition 2 : If, for all ingredients, the sum of the proportions of the agricultural and organic ingredients in the product divided by the sum of the agricultural ingredients is greater than 95%, condition 2 is met. 'B' must be greater than 95%.

$$B = \frac{\sum_{i=1}^{n} a_i * b_i * p_i}{A * w}$$

If condition 1 and condition 2 are met, then the product is organic.

Let's take the case of chickpea ragout. We choose this product because in the list of ingredients, the percentages are defined for most of the raw materials, so it allows us to have the most realistic example possible. Figure 24 below shows an example of the calculation to determine whether the chickpea ragout is organic.

The ingredients marked with an asterisk are those defined as organic by an inspection body. As not all percentages are mentioned on the product label, the values in red in the figure 24 have been chosen, following the logic of the list of ingredients, in order to be able to calculate them correctly. In addition, we dissociate salt from other spices because salt is not considered as an agricultural ingredient by definition. Whereas all other spices are agricultural and organic within this product. Spices are grouped together as a single ingredient. This decision is made for the sake of simplicity because the information on the percentages of these spices is not specified and it can logically be considered that the sum of these values is around 1%.

Let's detailed the figure 24. The middle table represents the list of ingredients provided on the packaging. It is structured in columns.

- The first column gives the name of the ingredient. When this ingredient is not raw material but a transformed product, its composition is detailed on the left table. Indeed, the calculation to make in order to see if the conditions are respected or not has to be done on raw materials.
- The second defines whether the ingredient is of agricultural (AG) or non-agricultural (NAG) origin according to the figure 2 or whether the ingredient is processed (has several ingredients of its own composition) (T).
- The third column defines whether the ingredient is organic or not. This is defined by organic certification.

- The fourth column gives the percentage of the ingredient in the finished product (the sum gives 100%).

The table on the left includes the raw materials for the two manufactured ingredients into the finished product (coconut milk and carrot pieces).

- The first column shows the percentage of the ingredients in the manufactured product. That is, the percentage of each ingredient contained in the coconut milk and carrot pieces.
- The second column includes the ingredient names.
- The third column defines whether or not the ingredient is of agricultural origin.
- The fourth column defines whether the ingredient is of organic or non-organic origin.
- The fifth column gives the percentage of presence of the ingredient in the finished chickpea ragout product. For example, carrots are 98% contained in the product carrot pieces. The product carrot piece itself is 8% found in the finished chickpea ragout product. Multiplying the two values, it can be stated that the raw material carrot is 7.84% present in the finished product.

Then we can calculate whether the product is organic or not on the basis of the conditions to be met. The light green columns in figure 24 show the percentages of the agricultural ingredients (AG). The dark green columns represent the organic ingredients (B).

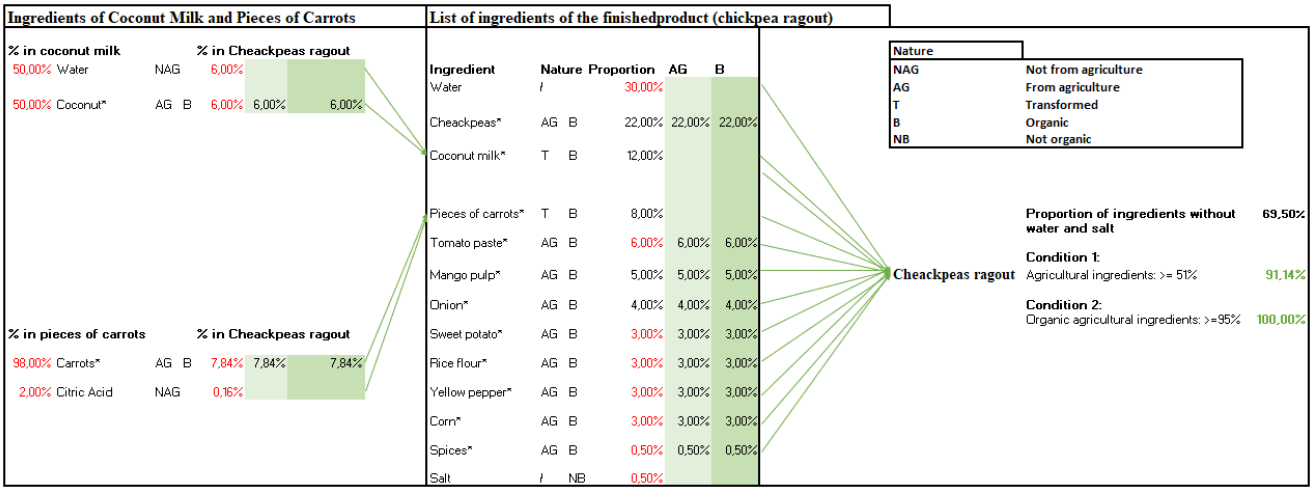


Figure 24: *Example of the calculation needed to determine if a food product is organic*

The figure 24 can be found more clearly in figure 28 in appendix e.

The calculations shown in Figure 24 are based on additions, subtractions, multiplication, divisions and conditions. All these operations are easily performed within smart contracts, which, when executed, will define whether a product is organic or not. Let us detail these calculations.

When we sum the percentage of ingredients within condition 1, we get a value of 91.1% ([6%+7.84%+22%+6%+5%+4%+3%+3%+3%+0.5%]/69.5%). The numerator considers the values on the light green columns. The value of 69.5% in the denominator corresponds to the sum of the weights (expressed as a percentage of the total weight) of the raw materials of the product minus the weight of salt and water (1-0.3-0.005=0.695 → 69.5%). Condition 1 is therefore met because 91.1% is greater than 51%.

We can therefore move on to the second condition where the sum of the percentages of agricultural and organic ingredients divided by the agricultural ingredients gives a value of 100% ([6%+7.84%+22%+6%+5%+4%+3%+3%+3%+0.5%]/[69.5%*91.1%]). The numerator considers the values on the dark green columns Indeed, in this case no ingredient is agricultural and not organic. As a reminder, it is very difficult to have a non-organic agricultural ingredient in a product because the regulations are very strict concerning these specific cases.

The information relating to raw materials registered within the user interface will be defined as organic or not by the producer. The operator profiles are digitally signed for the organic products once they have been controlled. Indeed, for raw materials, the organic character depends on an important number of factors that cannot be calculated with the help of a smart contract such as the respect of animal welfare, the restricted use of artificial fertilizers, ... The smart contract allowing to define whether a food (a transformed food) is organic or not will therefore use the information included in a previous transaction containing the information of a technical data sheet and thanks to the operations and conditions defined above, it will be possible to automatically define the organic character of a product.

However, it should be kept in mind that an organic product does not only mean that the food complies with the proportions of organic agricultural products and agricultural products. The food product must also comply with specific labelling rules and production rules that must be inspected in the field. The smart contract within the blockchain will make it possible to define whether a product is organic or not on the basis of its composition only. This is part of the conditions for a product to be organic but not the only one. It complements the official controls by the inspection bodies. Therefore, the calculation carried out by the smart contracts will make it possible to automate tedious operations.

4.8.2 Definition of the Organic Character of a Product for Each Actor

As explained above, the production of a food product can be defined as organic in its composition on the basis of automatic calculations carried out within a smart contract. When considering an entire supply chain (producer, manufacturer, trader), a farmer's production is defined as organic following official controls by organizations responsible for the European Organic Label. The profile of the operator on the user interface is defined as organic thanks to the digital signature of the inspection body for the products considered. The line of this raw material on a transaction profile is also declared as organic. The operator profile enables the manufacturer who wishes to purchase a batch of the production to know the organic character of the purchased goods. The mention of the organic character in the transaction profile enable all other operators to know that the product is organic. The manufacturer who bought the organic raw material of the farmer uses it to produce a food product that will be sold in different shops to the final consumers. If the product is processed in accordance with the two conditions for the production of a transformed food product defined in the smart contract, the production itself is automatically defined as organic in its composition.

Another smart contract can also be used in this case when the retailer purchases the manufacturer's production. Indeed, if the raw materials used by the manufacturer are organic and if the manufacturer's production follows the organic processing conditions, the retailer necessarily buys an organic product and the information line relating to this product bought by the retailer within the transaction profile can automatically be defined as organic.

Chapter 5: Challenges and Opportunities

This last chapter is dedicated to the analysis of the challenges and opportunities of the model built in chapter 4. We will first present these challenges and opportunities for each supply chain operator considered. Next, we will discuss several general opportunities and challenges for the development of the model.

5.1 Challenges and Opportunities for the Supply Chain Stakeholders

As mentioned in Chapter 3, the overall opportunities of using the blockchain in a food supply chain are data transparency, traceability of products in a fast and efficient way, better collaboration between stakeholders and data security. These features are globally beneficial for each actor in the supply chain.

Concerning the general challenges affecting all actors, the innovative infrastructure of the blockchain, its implementation cost and the collaboration are major challenges.

Let's detail for each actor the challenges and opportunities that are specific to them.

5.1.1 Farmers

Primary producers are a very important group of operators in our model as they provide information about the first operation in the supply chain. Without them, accurate traceability is not possible because the origin of the supply chain will not be included in the network. Unfortunately, they are also the actors most reluctant to consider the opportunities of using such technology. Indeed, they are operators that, according to an interview lead with La Ceinture Aliment-Terre Liégeoise, a priori operate the least with technology in their activities. This interview can be found in appendix f. As a result, for these actors particularly, a very user-friendly platform, if possible accessible via a smartphone, will be needed for them to record their information in real time. We have to emphasize that the use of this technology can ease their administrative workload to convince them.

The main advantage for this operator lies in the transparency of the information as well as traceability. Indeed, the model offers very good visibility to the food the farmer grows for consumers. Unfortunately, this can also be a disadvantage if the farmer offers imported products. With regard to traceability, the blockchain technology and the resulting transaction profiles will make it possible to find the source of a problem very quickly and thus to carry out recalls of problematic products. The risk of occurrence and the impact of a quality problem in the food supply chain will therefore be reduced through more efficient management.

5.1.2 Manufacturers

Manufacturers are surely the players with the most to win from being a member of this project. Firstly, a significant competitive advantage can result. Consumers will be excited to consult product data in a clear and transparent approach and this will influence their views on product quality and thus their purchasing behaviour. Secondly, manufacturers are the members to whom a system based on trust and information sharing could be most profitable. Indeed, they are at the centre of the chain and therefore have to process the information received and transmit their own information. This means dealing with documents received by suppliers, updating their systems and issuing documents to their customers. Thanks to the platform of the model, all these operations will be done within one system and in a digital way. The information will be available in a simple and fast manner. Another important advantage is the possibility of being able to trace the manufactured product upstream thanks to the transparency of the data.

Among the challenges that could block their desire to integrate this project is the disruption of current processes. The transformation procedures of products are complex, the processes set up within manufacturing companies are specific, the fear of disrupting these processes is a first challenge (Osei & al., 2018). It will be necessary to convince these actors that these processes will be simplified thanks to this project. Moreover, some manufacturing companies manufacture a lot of products and it may seem really difficult to register all these units in a new software system (Osei & al., 2018). For this reason, it will be necessary to create a relation between this new model and their ERP management system to facilitate the updating of the blockchain system with a tool with which they are familiar.

5.1.3 Retailers

Retail businesses are the operators who, in our model, are in direct contact with consumers. Therefore, an interesting opportunity for them will be precisely to take advantage of the characteristics of the blockchain from a marketing point of view. Indeed, the availability and reliability of information will attract consumers to these products.

An additional important point to mention is the power of merchants in the supply chain. Indeed, their sales volumes are very high, especially in supermarkets. This gives them a specific power that will either push the implementation of this technology or, on the contrary, stop it entirely (Osei & al., 2018).

5.1.4 Consumers

Thanks to this model, the consumer will have access to information that is not currently available to him, such as the origin of a product or even the path taken from its production to its sale. In the regulations, these are not data that have to be provided to final consumers but which, thanks to the model defined, will be available.

A challenge to be considered is the way in which the information is made available to consumers. Indeed, the user platform used by supply chain operators allows them to record data within the supply chain to which they belong. In the case of the consumer, he will need to have access to each blockchain ledger filled in by each company manufacturing a product and its stakeholders. The consumer will need to access this information in the simplest and quickest approach possible if we want it to influence their purchasing behaviour. Therefore, one solution would be to use a QR code system on each product linked to the blockchain system to which the product belongs so that the consumer can have access to the information.

This QR code system is currently used for pork in Carrefour supermarkets in Belgium and for chicken in Carrefour supermarkets in France (Carrefour, n.d) as well as by IBM (IBM, n.d).

5.2 Opportunities for the Development of the Model

5.2.1 General Opportunities of the Model

The model detailed in Chapter 4 can be considered simple but this is deliberate. Indeed, in this way it can be applied to any food supply chain. Therefore, as this model is general, it leaves space for many applications and therefore many opportunities. Some opportunities and challenges are taken into account in this section.

5.2.1.1 Internet of Things

The exponential technological development of recent years has enabled many innovative companies to develop their businesses digitally. Within supply chains and more particularly logistics, this is represented by technological tools for data collection such as the Internet of Things. The Internet of Things is defined as a network of objects connected to the Internet, communicating and sharing information between them on the basis of specific protocols (Patel, K & Patel, S, 2016).

Therefore, a first opportunity for our model, is one of the typical applications of the IoT that refers to logistics management through Radio Frequency Identification (RFID) (Tijan, Aksentijević, Ivanić & Jardas, 2019). RFID technology allows the automatic identification of moving objects without manual intervention. This technology is capable of storing and

managing information about these objects by a radio frequency signal. This is a great evolution compared to bar codes (Tian, 2016). As a result, when the company has sufficient technological development, each batch of goods can be equipped with an RFID chip that allows the information to be recorded automatically by the objects within the blockchain. Indeed, it is not feasible in the long run to consider that operators will manually insert all their information inside the platform. This leads to even more accurate transparency as well as a considerable benefit for real-time product traceability and monitoring.

The implementation of these RFID tags within our theoretical model will further facilitate the exchange of information between operators. Instead of each of them recording the information related to the receipt of goods for example, this same information will be automatically stored within a transaction thanks to the Internet of Things. The location of the goods in real time will be available and the traceability will be even more accurate. Moreover, this technology also makes it possible to provide details about the overall condition of a product and therefore its quality. It is also possible, for example, to record the storage and transport temperatures of products. These data can be recorded within transactions in blockchain and provide an additional degree of transparency in the food supply chain.

5.2.1.2 Sustainability

Growing demand, mass consumption and the desire of profit at all costs has led to increasing pressure on companies in all sectors and has resulted in many negative ecological and social impacts (Rajeev & al., 2017). In the context of the food industry, this translates into intensive production, soil pollution by chemical pesticides and fertilizers, animal welfare and antibiotic abuse, ever-longer supply chains and the emission of harmful gases, massive production of food waste, packaging waste, ... Every operator active in the food industry is affected by this unsustainable production, processing, distribution and consumption (Baldwin, 2011). Food supply is therefore an important factor in climate change. In addition, besides environmental concerns, the current economic model also has negative social impacts, particularly on consumer health through malnutrition, overeating and contamination, to which we can add the non-decent wages of employees, particularly in developing countries, the economic pressures on farmers, ... (Baldwin, 2011)

It is therefore important for every company active in the food industry sector to take sustainable development into consideration within its activity. According to the WCED (1987) the Sustainable Development is defined as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland,

1987). In order to assess a company's performance towards sustainable development, companies must take into account both social and environmental conditions in their activities.

An opportunity of the constructed model regarding sustainability would therefore be to use the underlying technology to assess a company's performance in relation to sustainable development.

Before detailing this opportunity, it is important to consider the ecological impact of the often-criticized blockchain. It is true that most public blockchains have a consensus algorithm that consumes a lot of energy (electricity). For example, within the Bitcoin blockchain, the consensus algorithm called Proof of Work requires a lot of computing power and therefore consumes a lot of energy. For the purpose of this paper, we consider a consensus blockchain with a limited number of participants in the network, so the energy-intensive nature (found particularly in public blockchains) is no longer an issue. Moreover, like every new technology, it could be criticized because the automation of certain tasks would eliminate jobs. It is true that some paperwork jobs may become useless in the future if this technology develops. However, the job creation potential that the use of blockchain within companies could create should not be underestimated. Indeed, many blockchain and smart contract specialists will be needed.

From a general point of view, the blockchain as a transparent shared register can be used to monitor the social and environmental conditions of companies. Indeed, as described in the model, each actor in the supply chain is integrated into the blockchain network. Its identity is known and it is easy to find out whether an actor has ever been part of a social or environmental problem.

More specifically, specific organizations may be part of the blockchain network to certify each operator, if it complies with certain ethical and environmental conditions defined previously, as respecting sustainable development. Then, thanks to smart contracts, a sustainability indicator for each supply chain and/or a sustainability compliance coefficient for each company/product within the food supply chain can be calculated. This could be done in a similar approach to the automatic calculations made within the code of a smart contract to define whether a product is organic or not. For example, thanks to RFID tags, it is possible to record the CO2 emissions emitted during the transport of goods within a smart contract. Thus, these records can be used to define an environmental pollution indicator for all transports from the producer to the final customer.

5.2.1.3 Performance Indicators

In Chapter 1.5, we discussed the four performance indicators characteristic of food sector supply chains. As a reminder, these indicators include efficiency, flexibility, responsiveness and quality. Most of these indicators can be measured using quantitative values or binary variables (yes/no, true/false). For example: production costs, shipping time, customer satisfaction, product quality, ...

Therefore, these indicators can be calculated within smart contracts so that each operator can have an individual reputation on his operator profile. Indeed, according to its relative performance on the different indicators and a weight associated to each of them, a percentage value can be calculated within the code of a smart contract allowing to assign a value, a percentage to each operator according to its flexibility, efficiency, reactivity and the quality of its products.

For example, when a producer or manufacturer records information about his production within the interface, this information is updated according to sales. As a result, it is possible to know at any time its stock level. On the basis of these stocks, an efficiency calculation can be made (for example, too much stock could mean inefficiency because few sales are made and a storage cost is associated with it). Then, the respect of delivery dates and of all specific conditions included in a smart contract representing a sale operation can be used to measure the flexibility and reactivity of an operator. Indeed, a supplier that respects all the conditions, no matter how different they are, of each contract demonstrates a certain flexibility and adaptability, which can also be taken into account in the calculation of the operator's reputation.

5.2.2 General Challenges of the Model

5.2.2.1 Cost

The cost of implementing this model can be a big challenge. Indeed, any change within a company involves a particular cost. In this case, we can consider that the cost of implementing this model will include: specialized programmers to create the blockchain protocol, specialized people who will explain the purpose of this change to each actor in order to convince them of the benefits of its use, specialized people who will programme the recording of each transaction throughout the use of blockchain and the programming of smart contracts (nodes). The investment for this project will therefore not be expensive to purchase but to maintain. The objective is to convince each user of the general advantages of using this technology and the reductions of other costs that it will also generate. Let's detail the maintenance cost of the blockchain.

In all the public blockchains allowing the exchange of cryptomoney, the nodes who build the block and who integrate it within the blockchain are paid thanks to cryptomoney. In the framework of our project, no financial transfer is made in cryptomoney and we have not dealt with the question of income yet. Indeed, we consider a team of nodes, in addition to the operators active in the food industry, which record transactions in blocks. Those nodes have to be paid in some way if we want this work to be done. It is reasonable to think that a company could exist to provide these nodes with the programming skills needed to record transactions. Unfortunately, at the present time, very few such companies exist to develop a model such as built in this thesis. This problem can also be a big challenge to the viability of our model. The solution would be to look at companies such as Hyperledger, for example, which have developed this kind of service. Unfortunately, we can assume that with these services companies the blockchain becomes rather centralised.

5.2.2.2 Technology Development

Many companies still operate with paper when exchanging information and sharing documents. They are not developed from a technological point of view, so it will be very complex to ask them to digitalize everything from one day to the next. Moreover, even if the blockchain appeared in 2008, it remains very innovative for all sectors. Very few companies are aware of this technology, its interests and trust the blockchain (Limbourg, 2019). It will be a lot of work to convince them.

For technologically developed companies, this is still a big challenge when considering the implementation of this model. Indeed, it is necessary to be able to find people who can implement it, able to programme a blockchain but especially to programme smart contracts. Fortunately, as mentioned before, some organizations have been offering blockchain services such as Hyperledger.

This model is also likely to lead to many changes within the companies participating in it, the organization of each company active in the network will be turned upside down. This is why a very user-friendly interface is needed.

On the other hand, as each user can use the blockchain through a decentralized application, one can logically be confident that each person active in the labour market has a smartphone or a computer through which he or she could connect to a decentralized platform. Unfortunately, in the food sector, this is more complex to assume. As mentioned before, primary producers barely have contact with technology in the context of their work, so it will be difficult to convince them of the value of recording their production information in an application.

5.2.2.3 Collaboration

The model built is based on the use of blockchain technology within the food industry sector so that each operator inserts his information in an interface in order to record it inside the blockchain technology. As a result, the model is based on the willingness of each player to share the information at their disposal. This means that it is necessary for each player to agree to share its information in order for the model to work. For example, if we take the case of tomato sauce, at the moment in the regulations there is no obligation to mention that tomatoes come from Spain. In the case of our model, the information will now be visible to the whole network because the profile of the tomato producer will be visible to several members of the network. If one actor does not see the point of sharing his data, the model is no longer relevant because it is based on transparent information sharing.

Moreover, blockchain technology, by its intrinsic characteristics, means that once the information recorded in a transaction is stored in a block, it cannot be modified, the data are immutable. This means that the possibility of fraud is reduced because the information once recorded cannot be modified or deleted. However, nothing prevents a dishonest actor from introducing false information into the block. For example, there is nothing to prevent a manufacturer of tomato sauce from misleading other actors about the composition of its product by mentioning that it is made with less salt than in reality. Worse, nothing prevents two actors in the chain from agreeing to mislead the other actors. For example, by mentioning that Actor 1, from Italy, sold tomatoes to Actor 2 from Belgium when Actor 1 actually bought his tomatoes in Turkey.

Conclusion

The objective of this thesis was to analyse the challenges and opportunities of using blockchain technology in a food supply chain with a special focus on organic food supply chains. Following the various food scandals that have occurred in recent years, we wondered whether this technology could be used to improve the exchange of information between operators.

Within this work, we first introduced the concept of food supply chain including details regarding the regulations applied to this sector. From this, we got an idea of the different information that each company has to provide to the control bodies as well as to other operators upstream or downstream in the supply chain. Several interviews gave us an idea of the different documents on which this information is available. Then, we detailed the principles of blockchain technology and how it works in general. These first two chapters gave an overview of the concepts. And the third chapter analysed the links between them.

We then graphically modelled the use of the technology within a food supply chain. A blockchain consortium and permissioned was conceptualized. Each operator in the supply chain being a user node. Validator nodes offering their services within the blockchain have also been defined.

After reading this paper, a global idea of the challenges and opportunities of using blockchain technology in a supply chain emerges. Among the opportunities there are: the transparency of data transmitted within a single platform without any intermediary between all the actors, the traceability of food products thanks to a regular recording of information by each actor within this platform, the improvement of the collaboration between actors thanks to the consensus algorithm governing the technology and data security ensured thanks to hash functions within and between blocks. Among the challenges, we find mainly the lack of technological development, the cost associated with the implementation of such a project and the need of collaboration in trust-based relationships between supply chain actors. Development opportunities are also mention such as sustainable indicator and performance indicator computation thanks to smart contracts.

We consider in this study that the actors know and trust each other. Indeed, it is necessary as all the stakeholders must agree on the rules governing this infrastructure. Therefore, they have to sit around a table to reach agreements. And thus, we don't have to keep the identity of actors anonymous. Above all, everyone must find an advantage in using this system. Indeed, if an operator no longer sees the benefit of collaborating in this project, he can

undermine it on his own. On the other hand, if they manage to build a protocol in a common approach, relations will improve between them and generate very strong collaboration through the transparent sharing of information between them. It is very important to ensure that the players are willing to move towards a better, more transparent supply chain. This is why collaboration can be a challenge as well as an opportunity.

The feasibility of using this technology in food supply chains therefore depends on several factors. Among them, mainly the technology and the collaboration of the actors. Therefore, for its implementation, it will be reasonable to consider a supply chain already developed in a technological way. It is not feasible to implement it with companies whose traceability records are still in paper format. It would also be more interesting to start with a manufacturing company that does not produce too many products, in order to avoid congesting the network with too many transactions. Therefore, with a limited number of products manufactured, the number of suppliers should not be too large either and therefore the number of players would be reasonable. This would make it easier to take decisions on the rules to be defined in the blockchain and the way the interface would work. The aim is not to implement this model directly in a complex network with a large number of products and actors. Regarding the feasibility of the project, it would also be more reasonable not to give consumers direct access to the network. It is firstly necessary to ensure that exchanges between operators are trouble-free. Finally, significant support from the control bodies will be necessary in the initial stage.

To conclude, we can say that the benefits of the blockchain are obvious for a large number of actors in the food supply chain. It is necessary to convince them. On the other hand, other discussions concerning technological integration, cost and the willingness of actors to participate must be pursued in order to have a complete vision of the implication of this model.

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Appendices

Appendix a. Glossary of Terms

Food Safety	Food control refers to a mandatory regulatory activity of enforcement by national or local authorities to provide consumer protection and ensure that all foods during production, handling, storage, processing, and distribution are safe, wholesome and fit for human consumption; conform to safety and quality requirements; and are honestly and accurately labelled as prescribed by law (Fao, n.d)
Regulation of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety	
Food – foodstuff – food product	Any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans.
Food business – food company	Any undertaking, whether for profit or not and whether public or private, carrying out any of the activities related to any stage of production, processing and distribution of food.
Primary production	The production, rearing or growing of primary products including harvesting, milking and farmed animal production prior to slaughter. It also includes hunting and fishing and the harvesting of wild products.
Royal decree from the 14 november 2003 related to 'Autocontrôle, notification obligatoire et traçabilité dans la chaîne alimentaire'	

Self-checking	The set of measures taken by operators to ensure that the products at all stages of production, processing and distribution and for which they are responsible : - Meet the regulatory requirements relating to food safety. - Meet the regulatory requirements relating to product quality, for which the Afsca is competent. - Meet the requirements on traceability and the monitoring of effective compliance with these requirements.
Identification	Any name and/or code that clearly and explicitly refers to the labelling of the product or to the registered data of a company, operator or holding unit.
Labelling	Any words, indications, brand names, images or signs relating to a product and appearing on any packaging, document, notice, label, ring or collar accompanying or referring to that product.
List of ingredients	Enumeration of all ingredients used (regardless of quantity). They must be mentioned with their specific name, in descending order of their weight at the time of manufacture.
<u>Directive of 13 December 2011 on indications or marks identifying the lot to which a foodstuff belongs</u>	
Lot	A batch of sales units of a foodstuff produced, manufactured or packaged under practically the same conditions.
<u>Regulation of 28 June 2007 on organic production and labelling of organic products and repealing Regulation</u>	

Operator	Natural or legal person responsible for ensuring that this Regulation is complied with at every stage of production, preparation and distribution that are under that person's control.
Competent authority	The central authority of a Member State competent for the organisation of official controls in the field of organic production in accordance with the provisions set out under this Regulation, or any other authority on which that competence has been conferred to; it shall also include, where appropriate, the corresponding authority of a third country.
Control body	Independent private third party carrying out inspection and certification in the field of organic production in accordance with the provisions set out under this Regulation; it shall also include, where appropriate, the corresponding body of a third country or the corresponding body operating in a third country.

Appendix b. Annex IX, Permitted Non-Organic Ingredients of Agricultural Origin

Edible fruits, nuts and seeds: acorns, cola nuts, gooseberries, maracujas, raspberries (dried), red currants (dried).

Edible spices and herbs: Pepper, horseradish seeds, lesser galanga, safflower flowers, watercress herb.

Others: seaweed, pea protein, rum (from sugar cane juice), specific kirsch.

Fats and oils whether or not refined, but not chemically modified, from plants other than: cocoa, coconut, olive, sunflower, palm, rape, safflower, sesame, soya, …

Sugars, starches and other products: fructose, rice paper, unleavened bread paper, starch from rice and waxy maize, not chemically modified.

Animal products: gelatine, whey powder, casings.

Appendix c. Explanation of the Hash Function

There are different hash functions. One of the most common is SHA256. The figures 25 below illustrate the use of the hash function for two different inputs. As mentioned in the chapter 2.3.1, we clearly see that the hash function transforms an input of arbitrary length in an output of fixed length. Moreover, this example shows that, even if the inputs have little differences, the output is totally different.

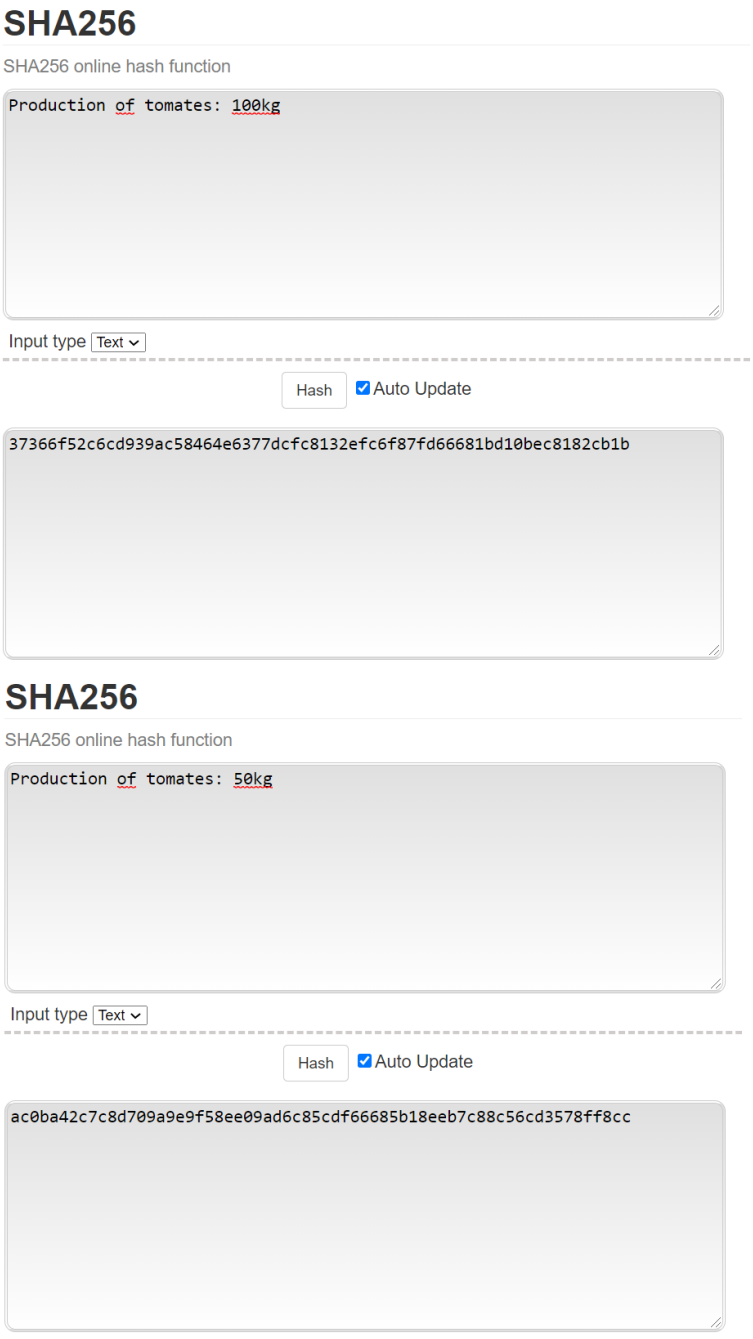

Figure 25: *Illustration of an example of the hash function SHA256*

Appendix d. Illustration of the Transaction Profile viewed by the Manufacturer and the Retailer

Transaction Profile												
Activity	**Identification number of the company**	**Product Name**	**State**	**Product ID**	**Origin**	**Ingredient List (% and kg)**	**Weight**	**Reception date and Sender (FROM)**	**Delivery date and Receiver (TO)**	**Access**	**Control**	**Organic**
R		P30	FP	id30	C30					R,A	Yes/No	Yes/No
C		P30	FP		C30					C,R,A		
M3	IDC30	P30	FP	id30	C30			D90 from IDC20		M3,R,A		
M2		P21	SF	id21	C21					M2,M3, A		
M1	IDC20	P20	SF	id20	C20	L5	KG	D50 from IDC10 D60 from IDC11	D500 to IDC30	M1,M3, A		
F8		P13	R		C13					F8,M2,A		
F7		P12	R		C12					F7,M2,A		
F6	IDC11	P11	R	id11	C11	L2	KG	D20 from IDC6	D200 to IDC20	F6,M1,A		
F5	IDC10	P10	R	id10	C10	L1	KG	D10 from IDC5	D100 to IDC20	F5,M1,A		

Figure 26: *Representation of the product profile for the manufacturer*

Transaction Profile												
Activity	**Identification number of the company**	**Product Name**	**State**	**Product ID**	**Origin**	**Ingredient List (% and kg)**	**Weight**	**Reception date and Sender (FROM)**	**Delivery date and Receiver (TO)**	**Access**	**Control**	**Organic**
R	IDC50	P30	FP	id30	C30	L7	KG	D93 from IDC30, IDC40		R,A	Yes/No	Yes/No
C	IDC40	P30	FP	id30	C30		KG	D92 from IDC30	D800 to IDC50	C,R,A		
M3	IDC30	P30	FP	id30	C30	L7	KG		D700 to IDC50	M3,R,A		
M2		P21	SF		C21					M2,M3,A		
M1		P20	SF		C20					M1,M3,A		
F8		P13	R		C13					F8,M2,A		
F7		P12	R		C12					F7,M2,A		
F6		P11	R		C11					F6,M1,A		
F5		P10	R		C10					F5,M1,A		

Figure 27: *Representation of the product profile for the retailer*

Appendix e. Calculation of Organic Production Condition

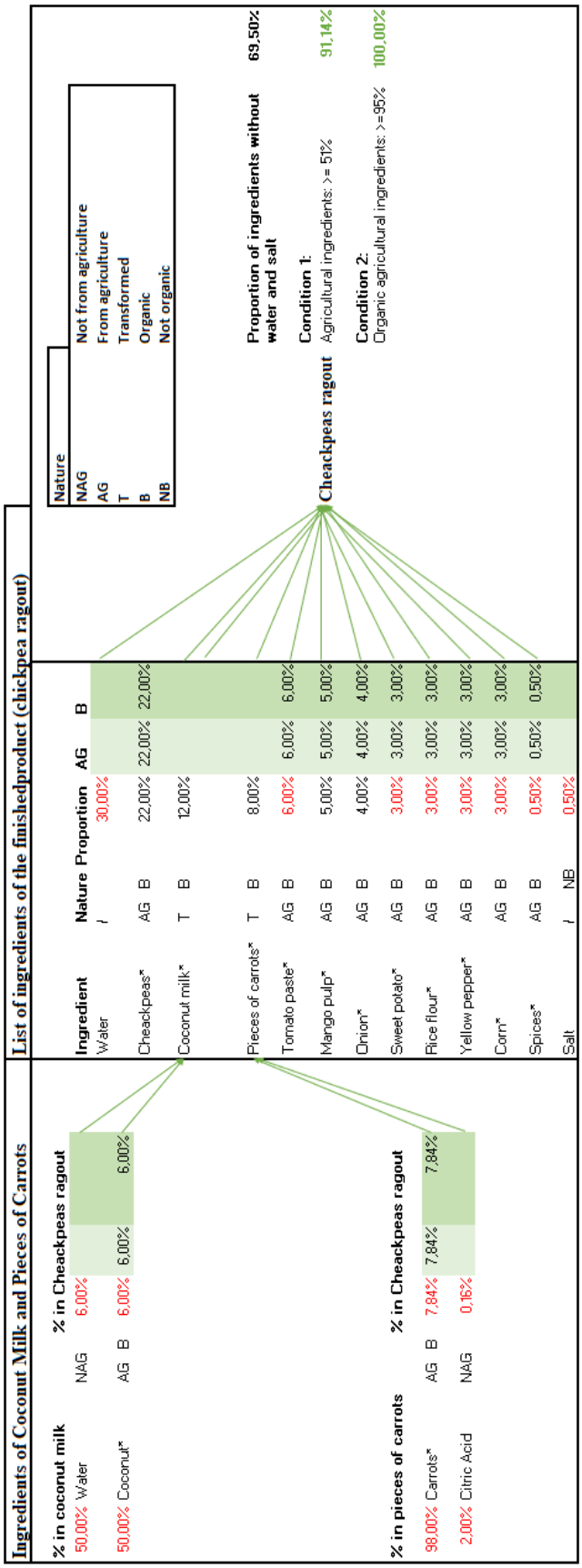

Figure 28: *Example of the calculation necessary to determine whether a food is organic*

Appendix f. Interview Results

Name	Company	E-mail	Reasons
Eric Sonnet	SPF Economie	Eric.Sonnet@economie.fgov.be	Food Regulations
Maud Quaniers	Belourthe	maud.quaniers@belourthe.be	Information Flows in Food Supply Chain
Quentin Lecaillié Didier Hanin	Salminvest	quentin@salminvestgroup.be Phone number	Information Flows in Food Supply Chain
Vincent Weytjens	Sainte Nitouche	Vincent Weytjens	Information Flows in Food Supply Chain
Jean Marc Michalowski	Ceinture Aliment-terre Liégeoise	jmm@catl.be	Actors in the food supply chain in the Liège area
Pierre Denis	Afsca	INFO.LIE@favv-afsca.be	Food Regulations
Pierre Hennebert	Certisys	pierre.hennebert@certisys.eu	Organic Food Regulations
Bénédicte Henrotte	Biowallonie	benedicte.henrotte@biowallonie.be	Organic Food Regulations

Interview with SPF Economie

- ***Les ingrédients au sein d'une liste d'ingrédients étant classés par ordre décroissant de poids, comment font les entreprises pour classer les ingrédients d'un produit fini lorsque les matières premières sont des produits transformés (exemple d'une lasagne : matière première : fromage, pâtes, sauce tomate, …) ?***

Le pourcentage des ingrédients d'un produit est transmis à un opérateur de manière contractuelle. Au sein du contrat est établi le cahier des charges du produit en question. De ce fait, l'opérateur acheteur peut justifier la liste des ingrédients de son produit en fonction du cahier des charges des marchandises achetées. Il n'y a pas de document officiel qui reprend les ingrédients des produits achetés, c'est une question de bonne foi. L'opérateur fabricant le produit à destination du consommateur final est responsable de la liste des ingrédients envers le consommateur.

Il est parfois très compliqué de construire une étiquette comprenant la liste des ingrédients. En effet, le poids d'un composant peut varier en fonction de son état (cuit ou cru). De ce fait, il y a une certaine tolérance de marge sur la mesure du poids des composants d'une denrée alimentaire.

Lors d'un contrôle alimentaire des analyses sont faites pour vérifier par exemple, lorsqu'il est indiqué que la denrée contient de la viande de bœuf, si c'est bien de la viande de bœuf. Par contre, aucune analyse n'est réalisée pour vérifier si l'ordre des ingrédients dans la liste des ingrédients correspond aux poids approximatifs contenus dans la denrée. En effet, ces prises d'échantillon posent un problème de nature budgétaire car le cout d'analyse est important et serait aux frais de l'état.

- ***L'origine d'un produit acheté est-elle connue par tout opérateur ? Doit-elle être transmise aux consommateurs ?***

Fruits et légumes : il est obligatoire d'indiquer l'origine et la catégorie. Un règlement d'exécution impose cet affichage que la marchandise soit préemballée ou non.

Viande : l'origine est obligatoire seulement pour la viande préemballée mais pas pour les viandes de boucherie (cela peut être mis de manière facultative mais si l'information est mentionnée, elle doit être correctement mentionnée). L'animal peut être abattu, né et élevé à trois endroits différents, cela devra être mentionné.

Poisson : Le lieu (par exemple : Atlantique + code) doit être indiqué ainsi que l'espèce (son nom en latin), le lieu de pêche (et le type d'engin de pêche) ou d'aquaculture (pays où l'élevage est réalisé).

Produits transformés : il n'y a pas d'obligation d'indiquer l'origine des ingrédients. Certains pays européens veulent le faire (pour les produits laitiers par exemple) mais cela a été abandonné. Depuis le premier avril, il y a une obligation, en Belgique, d'indiquer l'origine des ingrédients primaires dans certaines conditions. Par exemple, pour un chocolat désigné d'origine belge, il faut indiquer l'origine des ingrédients composant le chocolat. C'est une réglementation récente (toujours en phase de questions et réponses).

Cas d'orange et de jus d'orange : pas d'obligation entre commerçant de mentionner l'origine des oranges, sur les factures aucune indication obligatoire de mentionner l'origine. Dans le cadre des oranges, ils sont obligés de le faire car l'information doit être disponible au bout de la chaîne c'est-à-dire pour les consommateurs. Dans le cadre du jus d'orange cette obligation n'existe pas. De ce fait, il n'y a pas de sanction si l'information n'est pas partagée.

Interview with Belourthe and SalmInvest

- ***Comment détaillez-vous la liste des ingrédients d'un produit dont les ingrédients de base sont des produits transformés ?***

SalmInvest : ils fonctionnent via des fiches techniques détaillant la composition du produit acheté. Le fournisseur envoie la fiche technique avec le détail de la composition de son produit. Quand SalmInvest produit sa propre marchandise, ils ajoutent à leur propre fiche technique leurs ingrédients utilisés en plus des ingrédients composant les produits achetés. Et ils calculent eux même les nouveaux pourcentages des ingrédients composant leur produit. La communication de cette fiche technique se fait après la demande de prix. Ensuite, ils reçoivent un échantillon du produit demandé. Ils fournissent leurs fiches techniques également à leurs clients.

Belourthe : Ils se basent sur les spécifications fournies pas leurs fournisseurs dans les fiches techniques transmises. Ils indiquent la denrée alimentaire dans leur recette en fonction de son pourcentage d'incorporation et entre parenthèse ils indiquent les ingrédients de cette denrée dans l'ordre annoncé par le fournisseur.

- ***Comment complétez-vous vos registres d'entrées, de sorties, comment assurez-vous votre traçabilité interne ?***

SalmInvest : Le livreur dispose d'un bon de livraison (se constituant de la dénomination du produit, conditionnement, quantité, volume…). Toutes les informations relatives au produit sont stockées dans leur ERP lorsque la marchandise est réceptionnée. De plus, les conditions du transport sont transmises (air ambiant, chaîne du froid…). Si les produits sont transportés dans un camion réfrigéré, l'entreprise contrôle si cela a bien été le cas à la réception, le réceptionniste regarde si la température du produit est conforme.

Pour la traçabilité interne, leur système ERP gère ça lui-même. La marchandise est enregistrée dans leur ERP quand elle est réceptionnée et le système est mis-à-jour lorsque la marchandise est utilisée lors de la production d'un produit. Ils justifient dans quel lot la marchandise a été utilisée. Le stock est décompté et la date d'utilisation est mentionnée. Leur traçabilité interne retrace toute la vie du produit à l'intérieur de leur entreprise, c'est-à-dire les quantités utilisées pour tel produit avec tel numéro de lot, … Ces informations sont notées dans l'ERP. Tous les jours, les ateliers clôturent les ordres de fabrication et le système ERP est mis-à-jour.
Pour la traçabilité générale, c'est-à-dire enregistrer l'entreprise ayant envoyé la marchandise et celle qui recevra le produit après le traitement en entreprise, ils ont une base de données composée des différents fournisseurs et clients.
La procédure de référencement des fournisseurs se déroule comme suit : une commande test est effectuée afin de valider la marchandise, ensuite le fournisseur est référencé.
La traçabilité est réfléchie à l'envers, c'est-à-dire que le point de départ est le numéro de lot du produit fini, ce numéro leur permet de retracer les opérations effectuées jusqu'au moment de la réception de la marchandise utilisée chez eux. S'il y a un souci important, ils fournissent le numéro de lot reçu à leur fournisseur et lui-même regarde sa traçabilité interne.
Belourthe : ils ont un système ERP qui leur permet d'encoder toutes les entrées et sorties de matières.

- ***Quels sont les échanges d'informations (documents) entre vous et votre fournisseur/distributeur ?***

SalmInvest : Parmi les documents, ils retrouvent le bon de livraison (note d'envoie) et la facture. Il y a également le CMR qui est un document de transport rempli par le transporteur. Il est utilisé que ce soit pour un transport national ou international. Des documents supplémentaires de dédouanement sont utilisés dans le cadre des commerces internationaux. En ce qui concerne les contrats entre eux et leurs clients, dans certains cas ce sont des contrats à l'année par exemple pour les grandes distributions. Pour les grossistes, il n'y a pas vraiment de contrat, ils peuvent arrêter quand ils le veulent.
Belourthe : Ils reçoivent un CMR de livraison et un certificat d'analyse de leur fournisseur. Ils envoient à leur client dans la plupart des cas, un bon de livraison, un CMR et un certificat d'analyse.
Les certificats d'analyses reprennent la liste des résultats analytiques réalisés sur chaque produit en fonction de leurs demandes, il peut s'agir de résultats nutritionnels, de résultats microbiologiques, ou encore de résultats sur les pesticides et les métaux lourds.

- ***Comment s'organise le transport de marchandises ?***

SalmInvest : Le fournisseur s'occupe du transport de chez lui à chez SalmInvest et l'entreprise prend en charge le transport de chez eux à leurs clients. Pour l'international, ce sont les clients qui gèrent le transport (au-delà des pays limitrophes comme la France ou les Pays-Bas par exemple). SalmInvest sous-traite le transport à une société externe.

Belourthe : Leurs clients et fournisseurs sont généralement responsables du transport depuis et vers leur usine.

Interview with Sainte Nitouche

- ***Disposez-vous de fournisseurs différents pour chaque ingrédient ?***

Oui.

- ***Est-ce qu'il est déjà arrivé qu'un fournisseur soit à court de marchandises et que vous deviez commander chez un autre fournisseur ?***

Oui. Ils disposent d'un deuxième ou troisième fournisseur potentiel pour beaucoup d'ingrédients.

- ***Vos fournisseurs se connaissent-ils entre eux ?***

Oui, Sainte Nitouche les met en concurrence pour avoir le meilleur prix mais généralement les prix restent très proches du prix du marché.

- ***Comment s'organise un contrat entre vos fournisseurs et vous ?***

Le plus souvent il n'y a pas de contrat excepté pour les bouteilles en verre achetées.

- ***Disposez-vous de fiche technique pour chaque ingrédient ? Quand recevez-vous ces fiches techniques ?***

Les fiches techniques sont demandées pour chaque ingrédient acheté mais il n'est pas facile de les avoir. Ils font toujours la demande pour compléter les dossiers (demandé par l'Afsca). Mais les fournisseurs n'en réalisent pas toujours. De ce fait, la présence de fiches techniques est un élément de sélection du fournisseur.

- ***Quels sont tous les documents que vous échangez avec vos fournisseurs/clients ? Est-ce que ce sont tous des documents légaux ou y a-t-il des documents que vous échangez de manière volontaire ?***

Les listes de prix sont transmises via des tableaux Excel. Tous les échanges se font par e-mail. Lors d'une commande, il y a une confirmation de prix et une fixation de la date de livraison. La facture et le bon de livraison sont émises par la suite.

- ***De quels documents proviennent les informations que vous devez enregistrer dans vos registres d'entrées, registres de sorties et traçabilité ?***

Du bon de livraison ou de la facture au lieu du bon de livraison.

- ***Vous occupez-vous vous-même du transport de vos marchandises ? Quels sont les documents de transport dont vous devez disposer ?***

Ils s'en occupent pour la région Liégeoise et sous traitent pour l'export et le reste de la Belgique. Les documents sont : le bon de livraison et le CMR.

- ***Vos clients connaissent ils vos fournisseurs ?***

Pas vraiment. Ils peuvent en parler dans une discussion mais ce n'est pas une question demandée par les clients. Cependant la connaissance de cette information n'est as problématique. S'ils cherchent, ils trouveront facilement.

Interview with Ceinture Aliment-Terre Liégeoise

- ***Quel est le rôle de la Ceinture Aliment-Terre ?***

Aider à la création ou cocréer des projets alimentaires de circuit court dans la région de Liège. D'après la Ceinture Aliment-Terre, un Circuit court est défini par une distance kilométrique ou un nombre d'intermédiaire. Dans le cas de Liège, le rayon équivaut à 50km ou à la région de Liège dans sa globalité.

- ***Traitez-vous avec de grandes enseignes ?***

Traiter avec la grande distribution n'est pas l'objectif.

- ***La qualité des produits dans le secteur de l'alimentaire est très importante. Savez-vous quelles sont les différentes régulations pour garantir une certaine qualité ?***

Le contrôle de la sécurité alimentaire est assuré par l'Afsca. Les contrôles sont aléatoires ou prévenus. S'il y a un problème lors d'un premier contrôle, l'organisme de contrôle peut par la suite venir inopinément dans l'entreprise en question pour voir si le problème est réglé.
Normalement ces contrôles ont lieu tous les deux ans pour les maraichers. Pour des secteurs comme la viande par exemple, cela peut être beaucoup plus fréquent (deux fois par semaine).
Tous les formulaires de contrôle sont disponibles sur le site de l'Afsca. Chaque opérateur de la chaîne alimentaire peut préparer son contrôle Afsca avant le contrôle.
Toute personne active dans la chaîne alimentaire (préparation/transformation/vente) doit s'inscrire volontairement à l'Afsca.
Pour un contrôle de base chez un maraicher, ils contrôlent les factures, l'achat de produits chimiques, le respect des règles d'hygiènes, …
Chaque opérateur doit avoir un système d'auto-contrôle qui permet de vérifier tout une série de choses, toutes les mesures misent en place pour s'assurer de répondre aux règlementations. Toute entreprise de la chaîne alimentaire doit avoir développé son système d'auto-contrôle.
Dès que quelqu'un voit une non-conformité, il doit prévenir l'AFSCA.

- ***Quels sont les challenges/limites de la production biologique ou locale ?***

Les consommateurs. Produire biologique ou locale coûte plus cher car il y a une différence de qualité. Les consommateurs doivent être prêt à payer cette différence. Une entreprise de distribution a réalisé une étude et elle démontre que pour 30% de leurs clients, le prix est le seul critère d'achat, peu importe les qualités nutritionnelles, les origines, les OGM.

Un autre challenge est l'arnaque sur les produits. Par exemple, un maraicher peut acheter des carottes biologiques aux Pays-Bas et les revendre comme son propre produit.

Il y a également des problèmes techniques logistiques dans le cas de la production locale. Par exemple, les producteurs locaux peuvent avoir des problèmes pour pouvoir livrer en temps, en heure et en volume. De plus certains clients refusent les produits de par leurs esthétiques. Il y a également des problèmes d'accès à la terre, la terre agricole est devenue très cher. Elle reste captée par des grandes exploitations. En tant que maraicher, il faut de l'argent pour commencer une exploitation. Ils n'ont pas accès aux aides agricoles wallonnes ou européennes car ils ne remplissent pas les critères. Ils doivent commencer petit à petit, avoir un capital de départ, monter une coopérative ou un crow-funding.
Les supermarchés sont également problématiques car c'est toujours une question de rentabilité avec ces opérateurs. Ils vendent des produits locaux mais les remplacent par leurs propres produits ou les produits de grandes marques dès qu'ils le peuvent. Les petits producteurs doivent s'engager à livrer un certain volume qu'ils n'ont pas forcément ou alors ils doivent priver des plus petits clients.

- ***Que pensez-vous de la Blockchain dans le cadre d'une chaîne d'approvisionnement alimentaire ?***

Les producteurs utilisent simplement leurs téléphones et des carnets de notes. Il sera donc compliqué de leur demander d'utiliser cette infrastructure.
Concernant les circuits courts, la blockchain n'est pas un intermédiaire indispensable à leur communication car ils se connaissent tous et les relations sont très humaines.

<u>Interview with Afsca</u>

- ***Comment se déroule un contrôle standard chez un opérateur ?***

Un contrôle standard se concentre sur l'inspection de l'hygiène, les infrastructures, les installations dans lesquelles les denrées alimentaires sont manipulées, la traçabilité et l'étiquetage.

Ils travaillent avec des checklists, chaque checklist correspond à un contrôle spécifique comme le contrôle de la traçabilité, l'hygiène, l'étiquetage, …

Il existe 3 secteurs d'activité : la production primaire, la transformation et la distribution. Dans chaque secteur il y a un chef de secteur et des agents de contrôle.

Chaque fois qu'il y a une non-conforme des points s'additionnent. A la fin du contrôle, s'il y a moins de 20% de non-conformités non majeures, le contrôle est favorable avec remarque. S'il y a plus de 20% de non-conformités non majeures, il y a un avertissement. Pour des non-conformités supérieures à 20% dont certaines sont majeures, il y a un procès-verbal pour infraction.

Il existe également des contrôles par échantillonnage.

Sur base d'une analyse de risques, ils doivent prélever des échantillons tout au long de la chaîne alimentaire : de la ferme au fabriquant ainsi que le détaillant, ils couvrent toute la chaîne. Les prélèvements peuvent être réalisé pour analyser les métaux lourds, les pesticides…

Pour la traçabilité l'Afsca s'assure qu'ils peuvent remonter jusqu'à l'origine du produit chez l'opérateur que l'on contrôle c'est-à-dire jusqu'à la matière première qu'il utilise. Les documents permettant d'assurer la traçabilité seront différents en fonction de l'opérateur contrôlé, par exemple :

Grossiste : document qui confirme que la marchandise est arrivée chez lui.

Fabricant : factures d'entrées des différents composants.

L'Afsca ne sait pas contrôler tous les opérateurs de l'industrie alimentaire, ils procèdent donc par sondage pour déterminer quel opérateur et quel produit sera contrôlé. Et le contrôle s'effectue à plusieurs niveaux de la chaîne.

- ***Comment les contrôles se déroulent pour un opérateur qui produit une denrée alimentaire sur base d'ingrédients transformés ?***

Chaque niveau est contrôlé de manière découpé. Lors du contrôle d'un opérateur, son étiquetage est inspecté. Si pour étiqueter son produit il se base sur une information erronée, l'Afsca ne sait pas vérifier que cette information est fausse lorsqu'ils sont chez cet opérateur, c'est lorsque l'autre opérateur sera contrôlé qu'ils s'apercevront de l'erreur.

- ***Comment s'organise les opérations de contrôle pour une chaîne d'approvisionnement dont certains opérateurs sont à l'étranger ?***

L'Afsca contrôle les entreprises sur le territoire belge. Ils sont une entité fédérale. Le contrôle s'arrête avant l'importateur. Lorsqu'il y a une non-conformité en Belgique et que la source est à l'étranger, ils avertissent la commission européenne par un système RAS = rapid alert system for food and feed. La commission contacte à son tour l'état d'origine pour assurer le suivit.

- ***Quelles sont les fréquences de contrôle ?***

Les fréquences de contrôle dépendent de l'activité de l'opérateur et du risque. Si le produit alimentaire fabriqué est d'origine animale, la fréquence d'inspection sera plus élevée (plus que le commerce de détail dont l'activité est la vente). Pour les fermes, les inspections sont réalisées une fois tous les 8 ans. Les opérateurs actifs dans le secteur primaire (production animale et végétale) ont des fréquences de contrôle généralement peu élevées. Pour le secteur de la transformation, les fréquences sont élevées comme ils manipulent et distribuent beaucoup de produits. Le secteur de la distribution est contrôlé une fois par an car ils fournissent aux consommateurs finaux. Ils peuvent également être contrôlé par des vétérinaires indépendants.

- ***Les contrôles sont-ils prévenus ?***

Non.

- ***De quelles informations disposent chaque opérateur afin d'assurer sa traçabilité ?***

Les denrées alimentaires sont très complexes, il y a beaucoup de composants, ce n'est pas évident pour les opérateurs d'assurer la traçabilité de tous ces composants. Pour pouvoir avoir accès à ces informations, ils ont généralement des fiches de production.

Concernant les opérateurs actifs dans la grande distribution, ils auront simplement un bon de livraison reprenant les informations liées au produit. Le commerce de détail n'a pas accès à l'information concernant la provenance de tous les composants. L'Afsca eux-même regarde principalement à l'étiquetage dans ce cas-là (allergène indiqué, date de péremption indiquée, numéro de lot,… Tout ce que la législation impose.

Les ingrédients sont contrôlés au niveau de la fabrication et non de la distribution. Chez le fabriquant, il y aura la fiche de fabrication avec tous les ingrédients utilisés. En pratique, le fabriquant n'indique pas d'où l'ingrédient vient dans sa fiche de fabrication, il y aurait trop d'informations. C'est un document rempli dans les ateliers. Par contre, ils ont le numéro de lot du produit et grâce à ce numéro de lot, ils peuvent retrouver dans leur traçabilité quand et d'où le produit vient. Cela fait partie du contrôle traçabilité. Une traçabilité in et out doit être assurée. La première sert à prouver que le produit est bien arrivé chez l'opérateur (il faut également disposer de l'information concernant les ingrédients qui constituent le produit). La traçabilité out sert à démontrer que le client a reçu le produit et que les quantités enregistrées correspondent à celles reçues.

- ***Comment décririez-vous l'évolution de l'Agence ?***

L'Afsca a été créé après la crise de la dioxine dans les années nonante. L'idée était de refusionner des services différents qui ne collaboraient pas bien entre eux : agriculture,

inspection vétérinaire, inspection des denrées alimentaires, … Un système qualité a rapidement été mis en place. Des outils de contrôle ont donc été développés. Avant l'existence de l'agence, les contrôles étaient réalisés et des rapports étaient ensuite rédigés par les agents de contrôle. L'inspection était donc fortement soumise à la subjectivité du contrôleur. Désormais, l'agence travaille avec des checklists qui reprennent les obligations de la législation. Si la législation évolue, ils adaptent la checklist. Tout est informatisé, chaque agent a un ordinateur, il sélectionne le secteur de l'opérateur et la checklist apparait. Au terme du contrôle, il imprime le rapport.

L'Afsca est également accrédité ISO1720 et certifié ISO9020 ils sont donc dans le principe de l'amélioration continue. L'agence est auditée par l'OAV (office alimentaire et vétérinaire) afin de vérifier s'ils appliquent bien la législation européenne.

- ***Comment un opérateur se fait-il connaître de vos services ?***

Il est légalement obligatoire pour tout opérateur actif dans la chaîne alimentaire de déclarer ses activités avant de les commencer (ils doivent se faire connaître à l'Afsca).

De plus, en fonction de l'activité et du risque, soit l'Afsca enregistre simplement l'opérateur, par exemple s'il s'agit d'une ferme ou d'un commerce de détail vendant des denrées alimentaires pré-emballées à température ambiante. Soit ils fournissent une autorisation (pour tous les fabricants, grossistes sans produit animal) ou un agrément pour les niveaux d'exigence supérieure (viande, lait cru, œuf cru, pêche).

<u>Interview with Certisys</u>

- ***Pour les produits transformés, la règle est que 95% des produits agricoles présents à hauteur de 51% en poids dans le produit doivent être biologiques, comment s'effectue un contrôle afin de vérifier si cette règle est respectée ?***

Un produit biologique doit impérativement être composé de 95% en masse d'ingrédients d'origines agricoles certifiés biologiques. En outre les 5% restant ne sont pas n'importe quoi :

- Soit certains additifs issus d'une liste positive (l'annexe VIII A du 889/2008)
- Soit des ingrédients agricoles impératifs pour maintenir la spécificité de la recette, reconnus comme introuvables en qualité biologique sur le marché et cela doit faire l'objet d'une dérogation accordée par le ministère.

Ils confirment que certaines recettes sont plus complexes que d'autres au vu du process et d'une liste d'ingrédients.

La certification biologique est une certification de produit (différent de systèmes comme ISO par exemple) et qui dit produit dit recette. En amont cette dernière doit être conforme et prouver

que la personne va transformer des ingrédients certifiés biologiques avec un process également validé au préalable.

Ensuite, chaque année, par un système de contrôle mis en place par l'organisme de certification :

- Un bilan de l'activité biologique de l'entreprise sera contrôlé entre autres pour s'assurer que les recettes biologiques ont été respectées d'un point de vue qualitatif des ingrédients mais également un bilan quantitatif.

Pour ce faire ils consultent la comptabilité (achats et ventes ainsi que les données de stock) et le système d'enregistrement des mises en œuvre (fiche de fabrication).

- Des contrôles par échantillonnage inopinés sont également réalisés afin de contrôler de manière imprévue le respect des règles dans l'entreprise et des prélèvements pour analyse sont également réalisés où il est demandé aux laboratoires de détecter des produits non autorisés de manière biologique.

- ***Disposez-vous de fiches produits avec le poids de chaque ingrédient biologique afin de pouvoir vérifier si tout correspond à la législation ? Comment procédez-vous ?***

Le transformateur doit leur donner accès à la recette, sans cela ils ne peuvent vérifier la conformité et donc ils ne certifient pas. La recette est la base du contrôle pour cette activité.

Elle doit prouver que l'opérateur va utiliser des ingrédients biologiques.

Par exemple pour la sauce tomate :

Tomates biologiques XXXX kg

Épices biologiques XXXX gr

Poivre bio XXXX gr

Sel XXXX gr

Eau XXXX L

Pour les pâtes :

Farine de blé biologique XXXXX kg

Sel XXXX gr

Eau XXXX L

Executive Summary

Nowadays, the regulations applied to the food sector are becoming more and more stringent. They are regularly reviewed and updated in order to ensure the safety of the food chain in the most efficient way possible. However, safety problems still occur on a regular basis. The key is to be able to manage these problems without consequences for the health of consumers. Despite today's highly developed means of communication, it is often difficult to avoid the consequences of these problems. The recall or withdrawal of these problematic products is complicated to organize due to a lack of transparency and collaboration between the different actors in a supply chain.

The purpose of this paper is to analyse the challenges and opportunities of a data storage technology, the blockchain, in order to improve the sharing of information between the different operators of a supply chain with a focus on organic food supply chain. The usage of the blockchain within this work is to allow operators to share among other thingsf their production data in a transparent and secure distributed ledger as well as to automate some operations.

Through research in the scientific literature and interviews with experts and companies active in the food sector, this paper outlines the characteristics of the food sector and the details of the regulations as well as the principles governing blockchain technology. On the basis of this literature review, links are established between the concept of food supply chain and blockchain. A graphical model illustrating the use of blockchain within a food supply chain is constructed and allows to represent a model of information sharing between operators using blockchain technology. Among the opportunities of this model, we find the transparency of the data allowing a better traceability, an improvement of the collaboration between the actors as well as the security of the transmitted information.

Some conditions are essential to the implementation of such a project and can be very challenging in its development. Among these conditions we find the need for a good basis of collaboration and trust between the actors so that they agree to share information. In addition, companies must have a minimum level of digitalization in order to be able to consider this project. At the present time, the technology is not yet sufficiently known by the operators of the food supply chain. It would be necessary to initiate discussions with stakeholders in order to demonstrate the benefits of this technology.

LIST OF KEYWORDS: *Supply Chain – Blockchain – Distributed Ledger – Smart Contract – Technology – Information – Food – Food safety*