University of Zurich[UZH]

When two chains converge: How blockchain technology transforms food supply chains

GEO 511 Master's Thesis

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30.11.2020
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I Acknowledgements

My sincere thanks go to all the people who facilitated this master thesis:

First and foremost, I would like to express my sincere gratitude and appreciation to my supervisor Prof. Dr. Christian Berndt from the Economic Geography Department of the University of Zurich. He gave me the freedom and encouraged me to choose a research topic that fully meets my idea of a purposeful research. I appreciated his valuable feedback and guidance that helped me to organize and realize this thesis.

Special thanks go to all interview partners that took time out of their busy schedules to answer my questions. Without their helpful contribution, I would not have been able to gain practical and personal insights that were required for this research project.

Furthermore, I would like to thank my brother for the motivating exchange that helped me to critically reflect on my research. In addition, I sincerely appreciated his efforts in proofreading my thesis. Finally, I would like to thank my girlfriend and all my friends who supported me during the development of my thesis.

Table of content

II Figures

III Tables

IV Abbreviations

AI	Artificial intelligence
BFT	Byzantine fault tolerance
CAC	Code Alimentarius Commission
CIO	Chief information officer
CoC	Chain of custody
COVID-19	Corona disease 2019
CPS	Cyber-Physical Systems
DLT	Distributed ledger technology
DPOS	Delegated Proof-of-Stake
ERP	Enterprise resource planning
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GMO	Genetically modified organism
GPS	Global positioning system
GSM	Global System for Mobile Communications
GSCF	Global Supply Chain Forum
GVC	Global value chain
ICT	Information and communication technology
ILO	International Labour Organization
IoT	Internet of Things
ISO	International Organization for Standardization
ITU	International Telecommunication Union
IUU fishing	Illegal, unreported and unregulated fishing
NFC	Near field communication
NGO	Non-governmental organization
QR	Quick response
PBFT	Practical byzantine fault tolerance
PoA	Proof-of-Authority
PoS	Proof-of-Stake
PoW	Proof-of-Work
RFID	Radio-frequency identification
ROI	Return on Investment

SCM	Supply chain management
SDG	Sustainable Development Goals
SMS	Short message service
TCP/IP	Transmission Control Protocol/Internet Protocol
UK	United Kingdom of Great Britain and Northern Ireland
USA	United States of America
WHO	World Health Organization
WWF	World Wildlife Fund

V Abstract

Transparency and responsibility issues within food supply chains are serious concerns worldwide. Due to the growing world population, there is an increasing demand for food products, putting pressure on natural and human resources. Intensified food production has led to the degradation of terrestrial and aquatic ecosystems. At the same time, leading food companies profit from Global North-South disparities, whereas smallholders are exploited, furthering social inequalities. Hence, consumers increasingly demand to know how and where their products have been sourced. Yet, most food supply chains are complex and difficult to understand. To meet this demand in a more sustainable and efficient way, technological innovation is promoted in supply chain management. Thereby, blockchain technology may constitute a solution since it is gaining momentum in the food industry. Due to its immutability characteristic, blockchain offers the opportunity to shed light on opaque food supply chains by making all stages visible.

This thesis aims to evaluate the ways in which blockchain technology can be leveraged to optimize global food supply chain management by identifying current challenges and assessing the ways in which application of blockchain technology could yield viable solutions. For this, nine expert interviews were conducted with key players from the food industry and the blockchain related domain. This work suggests that if blockchain is harnessed in the right way, the technology can improve food supply chains in several regards. By enabling end user experiences and providing crucial information to consumers, consumer empowerment and a responsible consumption is promoted. Moreover, due to the digitalized record bookkeeping, food companies benefit from efficiency gains in various ways. Thus, blockchain-enabled traceability systems address claims for a dynamic management of logistics throughout supply chains in real-time. Furthermore, companies can better comply with food safety regulations and prevent food fraud, while a reduction of operational costs is expected. However, many barriers and challenges exist that hinder widespread adoption of blockchain in the food industry for now. Amongst them, a lack of knowledge around blockchain among key entrepreneurs has been identified as a major hurdle, while regulatory frameworks are missing that promote interoperability standards between stakeholders. In addition, the interface between the digital and the physical world still poses a serious obstacle to overcome, while technical constraints regarding scalability persist. Finally, an outlook is provided regarding the future development of blockchain-based systems in the food industry.

1 Introduction

The world has seen great socio-economic progress that has come along with significant technological innovations in the last century. However, much of this progress has come at considerable social and ecological costs. Inequalities persist in terms of income, earning opportunities and access to basic goods (FAO 2018a: 24). Intensified food production has led to the degradation of terrestrial and aquatic ecosystems, while also contributing to climate change. Moreover, food waste and loss along the value chain of food put unnecessary pressure on natural resources (FAO 2018a: 19). Hence, much remains to be done to meet the 17 Sustainable Development Goals (SDG) of the Agenda 2030 posed by the Food and Agriculture Organization of the United Nations (FAO) in 2015 (FAO 2018a: 8).

Furthermore, transparency and responsibility of global companies seem to be serious concerns worldwide. There is a wide range of voluntary corporate responsibility initiatives addressing these concerns, while some are global, others are regional or sectoral (IOE, ICC, and BIAC 2006: 2). In Switzerland, citizen will vote in November 2020 whether to adopt or reject the Responsible Business Initiative (in German: Konzernverantwortungsinitiative). The initiative would require that international companies based in Switzerland to respect human rights and international environmental standards in foreign countries, as well. Thus, companies are required to carry out appropriate due diligence, which entails identifying real and potential risks, taking adequate measures to prevent violations, and assuming liability in case human rights or environmental standards are violated. In case of prosecution, however, companies will be exempted from liability if they can credibly demonstrate that they carried out all necessary measures to prevent the violations. Hence, this initiative has a preventive effect as it gives companies incentives to comply with their obligations (Corporate Justice 2018).

Traceability is becoming an increasingly urgent requirement in many supply chains due to sustainability concerns (Tian 2018: 64). Effective traceability systems can also substantially improve food safety, while food fraud and issues around complying with food regulations can be addressed (Banerjee 2017: 2).

Given that many information asymmetries along food supply chains prevail and production and trade are becoming increasingly globalized, food supply chains have become more complex (Kim et al. 2018: 335). This bears the threat of resulting in trust issues along food supply chains, such as fraud, corruption and manipulating information (Tian 2016: 4). Thus, it is not only difficult and important to comprehend supply chain processes for end consumers, but for its participating actors as well (Kim et al. 2018: 335). Yet, there is an increasing demand by consumers who are concerned about food safety and sustainability issues (Aung and Chang 2014: 182; Trienekens et al. 2012: 59; Wang, Han, and Beynon-Davies 2019: 71).

To meet the increasing demand for food products in a more sustainable and efficient way, research and technological change must be promoted in these fields (FAO 2018a: 19). The growth of information and communications technologies (ICTs) in the last decade has provided many tools to overcome some of the challenges faced in the food sector. Recent developments, such as the mainstream use of mobile broadband access devices, the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) have facilitated opportunities to improve production processes (Blaha and Katafono 2020: 1).

In this context, one of the most discussed technologies is blockchain technology, which is usually associated with cryptocurrencies in the financial sector. However, this technology can find usage in various further industries. Perhaps the most surprising one is the food and agriculture sector. In an industry where numerous trust issues prevail, blockchain technology may shed light on opaque supply chains and can help achieving the SDGs (FAO and ITU 2019: 7). Due to its tamper-proof record keeping nature, it has the potential to rewrite the rules for a sustainable food production (Cook 2018: 12). Furthermore, it can help empower small-holding stakeholders and consumers, improve food safety and diminish operational inefficiencies at the same time (Word Economic Forum 2018: 18). While blockchain is often regarded as a potentially disruptive technology (De Angelis et al. 2018: 1; Deloitte 2019: 13; FAO 2018b: 179; Natarajan, Krause, and Gradstein 2017: 53; Queiroz, Telles, and Bonilla 2019: 249; Treiblmaier 2018: 556; Wang, Han, et al. 2019: 79), it sometimes is misleadingly referred to as a sort of panacea that solves every problem at hand (van der Meulen 2018). According to Brigid McDermott, IBM’s vice president of blockchain business development, “blockchain is not solving a technical problem, it is solving a social problem” (as cited in Kamath 2018: 50).

As this thesis will show, food companies and retailers increasingly deploy blockchains with the intention to make their supply chain management (SCM) more efficient or to prove the superior quality to their customers. However, only a limited number of such use cases exist in the real business world since blockchain is still a relatively new and emerging technology facing various technological and organizational constraints.

This master thesis aims to demystify the blockchain technology within the realm of the food sector, present critical insights about the technology's opportunities, and identify unresolved challenges. Thus, various case studies within the food industry are presented that have deployed blockchain-based traceability systems. Whenever possible, this work refers to the tuna supply chain, for which four different blockchain-enabled projects were identified (White 2018; Whiting 2020).

1.1 Literature review

This section reviews the existing academic literature on blockchain in food supply chains. Despite the relative novelty of blockchain technology, it has been subject to extensive research lately. Yet, relatively little attention has been directed towards the applicability of blockchain technology and blockchain-enabled traceability for SCM (Galvez, Mejuto, and Simal-Gandara 2018: 230; Treiblmaier 2018: 553). Only a few scholars have discussed the emerging technology within the food sector (Galvez et al. 2018; Kamilaris, Fonts, and Prenafeta-Boldΰ 2019; Kim et al. 2018; Kshetri 2018; Queiroz et al. 2019; Wang, Han, et al. 2019). They present various ongoing food related projects for which blockchain has been deployed. The number of blockchain-based projects is limited, while most of them are still at a pilot stage and their long-term outcomes remain uncertain (Wang et al. 2019b: 77). Kshetri (2018) and Cole, Stevenson, and Aitken (2019) identified several existing industry examples for which blockchain-enabled solutions had been applied.

The main purpose behind blockchain in supply chains is the tracking of products. Thereby, full transparency and traceability can be enabled not only for involved parties along supply chains, but also for consumers. Thus, food safety issues and sustainability concerns can be addressed, while SCM is improved (Kamilaris et al. 2019: 647).

Several consultant companies have conducted surveys among entrepreneurs on how they perceive blockchain (Deloitte 2019; Furlonger and Kandaswamy 2019). Furthermore, guidelines had been elaborated that give advice on how blockchain should be deployed (FAO and ITU 2019: 16f.; Wust and Gervais 2018). Several NGOs and scholars have recognized the potential of blockchain as well and discuss its benefits for supply chains, whereas unresolved challenges and limitations around blockchain adoptions in the food industry are identified (FAO and ITU 2019; Furlonger and Uzureau 2019; Galvez et al. 2018; Kamilaris et al. 2019; Kshetri 2018; OECD and KPMG 2019; Wang, Han, et al. 2019; Word Economic Forum 2018).

Although blockchain technology is advancing rapidly, combining the physical with the virtual world poses a great hurdle to overcome (OECD and KPMG 2019: 18). In this regard, a far-reaching issue remains the missing verification mechanism of the raw data entering the blockchain (ibid: 19). Furthermore, Kshetri (2018: 88) sees the absence of regulations around blockchain as a major problem. This opinion is shared by several further scholars, while the immature technology and a lack of a clear return on investment (ROI) is addressed as well (Attaran and Gunasekaran 2019: 10; Kamilaris et al. 2019: 649). In addition, various security and privacy issues have been described (Galvez et al. 2018: 230; Kamilaris et al. 2019: 649; Wang, Han, et al. 2019: 77). The unpredictable costs of implementing blockchain technology represents another key hurdle (Galvez et al. 2018: 230). Moreover, there are environmental concerns as the operation of the network may require a high level of energy consumption (Wang et al. 2019b: 74).

While the benefits of blockchain technology have been widely discussed in the academic community, such research rarely focuses on the potential for unpredictable effects and unforeseen problems that implementation of this technology could give rise to (Treiblmaier 2018: 556; Wang, Han, et al. 2019: 79). Moreover, it stays uncertain for industrial stakeholders how their business can benefit from blockchain. Wang, Singgih, et al. (2019: 230) identified such a lack of understanding among business actors, which contributes to skepticism towards blockchain technology.

1.2 Research gap and research questions

Blockchain technology has received substantial amount of interest from researchers and practitioners. Nevertheless, its potential business applications in the food sector remain under-researched (Chang, Iakovou, and Shi 2020: 2082; Galvez et al. 2018: 230; Kshetri 2018: 81; Saberi et al. 2019: 2118; Stiller et al. 2019: 72; Treiblmaier 2018: 553). There is limited evidence of how existing food supply chains benefit from the blockchain (Wang, Han, et al. 2019: 65). Although many challenges around realizing blockchain in food supply chains have been described, no detailed information about its practical implementations have been reported yet (Galvez et al. 2018: 230). Further, the aforementioned literature does not contain any proposed solutions that would address these challenges. Moreover, no literature was found that discusses the opportunity posed by blockchain for certifying ecolabels.

In this sense, this work aims to better understand the blockchain technology, its opportunities and its application fields in food supply chains. This understanding begins with an assessment of the concepts upon which blockchain technology is built, and the current state of its technological advancement. Furthermore, this work identifies unresolved challenges, while potential solutions are suggested to overcome some of these problems. Finally, this work provides an outlook to what extent the blockchain technology might transform the food sector. This comprises the consideration of potential impacts on all actors across food supply chains, including third party service providers such as certifying ecolabels.

For this master thesis, the following research questions have been elaborated:

- How does the blockchain technology assist food supply chains and who are the beneficiaries?
- What are the remaining challenges around blockchains in the food industry and how could they be addressed?
- To what extent can the blockchain technology transform the food industry?

1.3 Structure of the work

This master thesis is structured into seven chapters. After the introduction in chapter *1*, three relevant bodies of relevant theoretical literature describing respectively digitalization, supply chain management and global value chains are presented in chapter *2*.

Chapter *3* presents the methods that had been applied for this thesis. This includes the data acquisition and data analysis.

Since blockchain is a rather complex technology, chapter *4* explains its architecture and components in depth. Understanding the different blockchain types and its underlying concepts is necessary background to be able to answer the first research question. Thereby, a first impression regarding the technology’s potential is presented by examples of existing applications within various industries.

Chapter *5* introduces how blockchain is deployed within food supply chains. The real use case of the tuna industry demonstrates how a commodity's supply chain can be optimized with components of blockchain technology. Furthermore, several other commodities and use cases are presented, while the blockchain's benefits are discussed at the end of chapter *5*.

Chapter *6* identifies the limitations and unresolved challenges related to blockchain and proposes solutions to overcome some of these challenges, thereby answering the second research question. In addition, the blockchain's two main purposes – traceability by end users and supply chain internal traceability – are illustrated and finally compared and assessed with a synthesis. Moreover, potential transformations of traditional food supply chains are discussed. This includes disintermediation, the increasing credibility of ecolabels and the opportunity to change value chains by supporting small-sized companies and smallholders in developing countries. Finally, an outlook regarding the blockchain's future applications in the food sector is provided that is based on the interviewees' statements and perceptions.

Chapter *7* summarizes the most important findings that answer the research questions. Finally, an outlook regarding future research fields is proposed.

2 Theoretical background

The proliferation of digitalization within supply chains has led to the restructuring of complete value chains. The internet had a significant impact on SCM, creating digital marketplaces, realizing cost reductions, increasing productivity, and allowing the creation of customized services. Blockchain offers similar promises (Treiblmaier 2018: 545). To better understand the context of this realm, related key terms and concepts are clarified in this chapter. First, the concept around digitalization is explained. Second, the framework of SCM and finally the concept of global value chains is presented. The underlying concept of the blockchain technology is described in chapter *4*.

2.1 Beyond digitalization: Industry 4.0

In the last 50 years, there has been a massive progress in the fields of information technology (Thun et al. 2019: 39). According to Graham (2019: 3), "digital information, or data, is one of the fuels of the new economy." Hence, *digitalization* has been identified as one of the major drivers that change society and business in the near and long-term future (Neumeier, Wolf, and Oesterle 2017: 484; Parviainen et al. 2017: 64). At this point, the term digitalization, or elsewhere referred to as *digital transformation*, needs to be clarified and distinguished from the term *digitization*. Although these two terms are related and some authors use these terms interchangeably (Graham 2019; Hirsch-Kreinsen 2016; Schneider 2018), each of them has its own distinctive meaning. Digitalization defines "the changes that the digital technology causes or influences in all aspects of human life" (Stolterman and Croons Fors 2004: 689). Therefore, digitalization describes a fundamental change, while digitization, on the other hand, is referred to as the process through which analogue data, such as documents, images and videos, is converted into digital form (Parviainen et al. 2017: 64; Ringenson et al. 2018: 5).

ICTs laid the groundwork for the third industrial revolution around the 1970s (Rifkin 2011: 35), which is commonly known as the *digital revolution* (Schneider 2018: 806). ICTs are the basis for modern processes, while its widespread impacts can be seen in the highly automatized industry production (Drath and Koziolek 2015: 2).

The first industrial revolution was characterized by mechanical production facilities in the second half of the 18th century, while electrification and the increasing division of labor (i.e. Taylorism and Fordism) led to the second industrial revolution after 1870 (Hermann, Pentek, and Otto 2016: 3929). According to some scholars, the digital revolution is the last and current of the great industrial revolutions (Rifkin 2011: 6). However, the concept of *Industry 4.0* has evoked the debate whether the world is facing a fourth industrial revolution. Although the term was introduced in Germany in 2011 to promote the competitiveness of their national industry (Drath and Koziolek 2015: 28), its concept has been adopted by numerous international scholars in the meantime (Queiroz et al. 2019: 244; Schneider 2018: 810). Even the World Economic Forum in Davos, Switzerland, chose Industry 4.0 as the leading theme for the 2016 conference, which emphasizes the importance of this phenomenon (Schneider 2018: 804). The debate around the concept of Industry 4.0 is insofar notable as for the first time, an industrial revolution is forecast before its underlying components have been realized (Drath and Koziolek 2015: 3).

On the one hand, Jasperneite (2012: 28) claims that this current debate is just "new wine" being poured into "old bottles". He argues that technological systems such as ICTs are not new since current innovations are still based on the same technologies. On the other hand, the fourth industrial revolution seems to go beyond pure digitalization. It rather builds upon this concept, while it may be interpreted as a technological prerequisite for Industry 4.0 (Schneider 2018: 806).

The difference between digitalization and Industry 4.0 becomes apparent when the underlying concepts are studied. Within digitalization, manufacturing becomes computerized. However, its embedded networks are isolated and thus unconnected. Their range of applications is limited to optimizing the performance of a particular object in which they are integrated (Schneider 2018: 807). The premise behind Industry 4.0, on the other hand, suggests that connecting embedded networks can drive improvements in efficiency and productivity. The Internet of Things (IoT) and Cyber-Physical Systems (CPS) are key components for Industry 4.0. IoT enables "things", such as radio-frequency identification (RFID), sensors, actuators and smart phones that share information and interact with each other (Hermann et al. 2016: 3929; Thun et al. 2019: 41). CPS is an information technology that is based on IoT. It interconnects distributed and embedded networks via communication infrastructure such as the internet. Thereby, the virtual and the physical world is merged. To be more specific, CPS can be understood as "smart" devices and equipment, but also as the management processes that are connected to advanced internet applications (Hirsch-Kreinsen 2016: 2). In this sense, Industry 4.0 comprises the networking of products (primary, intermediate and end products), means of production (e.g., machines) and actors (i.e., employees, suppliers and customers) in the value creation (Schneider 2018: 807). Thus, Industry 4.0 envisions a highly decentralized and flexible control of supply chains (Schneider 2018: 808). Compared to the digital revolution, Industry 4.0 strives for a completely new level of process automatization, which fundamentally provides new potential for production processes along value chains (Hirsch-Kreinsen 2016: 3). This, however, bears its pitfalls as technological advances will accelerate the pace of change for industrial workforce. Thereby, a further shift from repetitive and low-skilled work to more complex and cognitive tasks is expected (Thun et al. 2019: 42).

It is argued that for the first time, the fourth industrial revolution offers opportunities to overcome the world’s most pressing environmental challenges (Word Economic Forum 2018: 7f.) Moreover, Chou (2019: 108) points out that the primary focus during the first three industrial revolutions was to improve production efficiency. The fourth industrial revolution, on the other hand, comprises complex conflict interests among stakeholders that goes beyond economic efficiencies and addresses sustainability and socioeconomic concerns as well. Furthermore, he stresses that the interests of customers have moved beyond functionality and aesthetics. He describes a shift from passive and senseless to active and conscious customers. This shift, in turn, could drive more efficient utilization of production resources, as well as an increase in flexible mass customization and personalization (ibid: 109f.). In addition, leading companies have recognized the potential of gathering and analyzing data, which helps them to obtain detailed knowledge about their customers and identifying market trends. Thus, companies can differentiate themselves from competitors (ibid: 115f.). An efficient aggregating of such data and its analysis will increasingly play a key role in the food sector (Stiller et al. 2019: 7).

As chapter *4* lays out, blockchain addresses exactly the above-mentioned efficiency improvements and customer experiences. Blockchain is, therefore, regarded as a component of Industry 4.0 that is coupled with IoT and CPS (Queiroz et al. 2019: 246, 249; Word Economic Forum 2018: 4).

2.2 Supply chain management

SCM is a system that manages the flow of logistics and information throughout the supply chain – from the raw material to the end consumer. The sharing of key information amongst stakeholders is critical in achieving overall process optimization and in ensuring a smooth flow of goods. Furthermore, SCM is capable of rational planning and coordinating global supply chains, which helps its stakeholders to monitor and respond to occurring issues (Yoo and Won 2018: 2). The performance of SCM is usually measured in terms of quality, speed, dependability, cost and flexibility (Ho, Au, and Newton 2002: 4422; Kshetri 2018: 81).

However, there is no common agreement that defines SCM (Busch 2007: 442; Ho et al. 2002: 4416f.; Tan 2001: 39). Some see it as the management of purchasing and supplying (Tan 2001). Others see it from a logistical and transportation perspective, perceiving it as the management of materials, products and information flows from source to final user (Thomas and Griffin 1996). For this work, the terminology and definition of SCM stick to the framework provided by Lambert and Cooper (2000) as this is the only concept that highlights the management and the integration of business process across supply chains (Ho et al. 2002: 4421; Yoo and Won 2018: 2). The framework was developed by the Global Supply Chain Forum (GSCF), a group of academic researchers, and they introduced a new business model that creates competitive advantage by strategically managing business relationships (Lambert and Cooper 2000). Their framework suggests that the success of an individual business depends on the management's ability to establish and maintain business relationships (ibid: 65). The GSCF elaborated a definition, which had been slightly updated as the current one emphasizes the relationships in the network of organizations:

> "Supply chain management is the management of relationships in the network of organizations, from end customers through original suppliers, using key cross-functional business processes to create value for customers and other stakeholders."
> (Lambert 2014: 2)

The SCM framework consists of three interrelated elements: the supply chain network structure, the supply chain business processes, and the SCM components (Lambert and Cooper 2000: 69). Hereinafter, the three elements will be briefly described, though a primary focus is placed on the SCM processes which presents the greatest opportunity for utilization of blockchain technology.

The supply chain network structure includes all stakeholders that participate in a supply chain. For the SCM, it is important to explicitly know and understand its supply chain members and how they are linked to each other (ibid: 69).

Several authors suggest implementing supply chain business processes (Ho et al. 2002: 4422; Lambert 2014: 7; Yoo and Won 2018: 2). With standard business processes, actors across the supply chain use a common language, which facilitates an efficient collaboration. However, there is no industry standard that defines these processes yet (Lambert 2014: 7). In addition, Lambert and Cooper (2000: 72) identified eight SCM processes:

1. *Customer relationship management* identifies key customer groups as part of the corporate and marketing strategies. The goal is to segment customers based on their value over time and loyalty, for which products and services will be customized. Thereby, processes are improved and non-value-added activities are reduced (Lambert and Enz 2017: 7).
2. *Customer service management* provides information related to shipping dates and product availability to customers. It serves as an interface between customers and the organization's production and distribution operations (Lambert and Cooper 2000: 73). Thereby, the products and services are monitored and customer service management proactively intervenes on the customer's behalf in order to ensure the promises that have been made (Lambert and Enz 2017: 8).
3. *Demand management* is the SCM process that coordinates supply and demand proactively. Thus, variability in customer ordering is detected and reduced, while flexibility is increased (ibid: 8).
4. The *order fulfillment process* comprises all activities to design a network and enable a company to fulfill all customer requests, while maximizing profitability. This includes the strategic selection of production location and the analysis of import and export regulations (ibid: 8).
5. *Manufacturing flow management* optimizes flexibility in the supply chain, while products move into, through and out of the factories. The management evaluates the desired flexibility of strategic resources. According to the requirements of different customer segments, more than one supply chain configuration is necessary. For example, a lean supply chain focuses on efficiencies, while waste and variability are reduced, which is suitable for products with stable demand patterns (ibid: 8).
6. *Procurement* also referred to as *supplier relationship management* develops and maintains relationships with suppliers (Lambert and Cooper 2000: 73; Lambert and Enz 2017: 8). Here, key suppliers are identified in order to establish close relationships. Thus, a win-win relationship is pursued where both parties benefit (Lambert and Enz 2017: 8).

7. *Product development and commercialization* develops new products that are aligned with the customers' needs and brings them to market (ibid: 8).
8. Finally, *returns management* is the SCM process that deals with returns, reverse logistics, gatekeeping and avoidance. This includes unwanted returns and recalls due to performance failures (ibid: 8).

The SCM components are the third element of the framework and are managerial variables by which the SCM processes are integrated and managed across the supply chain. For SCM to be successful, the following nine management components were identified by Lambert and Cooper (2000: 77): planning and control, work structure, organization structure, product flow facility structure, information flow facility structure, management methods, power and leadership structure, risk and reward structure, and culture and attitude. Out of the nine components, the information flow facility structure component is key when considering the deployment of blockchain. Efficiency of supply chains rely on a frequent sharing of information. Hence, this component may be considered as the most important one (ibid: 78).

2.3 Asymmetric power relations along global value chains

Although the concept of the global value chain (GVC) shares similar characteristics as the one of SCM, it focuses on globally expanding supply chains and how value is created and captured. Gereffi and Fernandez-Stark (2011) provide a frequent definition for the GVC framework:

> "The value chain describes the full range of activities that firms and workers perform to bring a product from its conception to end use and beyond. This includes activities such as design, production, marketing, distribution and support to the final consumer." (Gereffi and Fernandez-Stark 2011: 4)

Within the GVC framework, globalization and *governance* are key elements (Gereffi and Lee 2012: 25). The latter can be defined as "authority and power relationships that determine how financial, material and human resources are allocated and flow within a chain" (Gereffi 1994: 97). In more simple terms, it describes how supply chains are organized and managed (Gereffi, Humphrey, and Sturgeon 2001: 4). Modernization and globalization of agriculture have changed relations between actors across food supply chains (Lawrence and Dixon 2015: 213). In this sense, globalization has led to a new era of international competition, which is reshaping the global production and trade. As such, regional productions have been increasingly replaced by global supply chains since the 1960s, a process that is referred to as *global outsourcing*. Thereby, low-cost and capable suppliers are hired offshore with a growing emphasis on East Asia. This in turn led to a fundamental shift from *producer-driven* supply chains to *buyer-driven* supply chains. In producer-driven chains, power is exerted by final-product manufacturers and capital-, technology- or skill-intensive production means are required. In buyer-driven chains, on the other hand, retailers or manufacturers of the final products hold the most power as they possess the ability to shape mass consumption through strong brand names (Gereffi and Lee 2012: 25). Increasing power concentrations in the retail and processing sector has been observed in the last 40 years, leading to buyer-driven global value chains (Gibbon and Ponte 2005: 122; IP5: 70). This has created a so-called *oligopsony* power where a few buyers negotiate with many sellers. For example, the food retail sector in the UK, France and the USA is each dominated by one lead firm (Tesco, Carrefour and Walmart) with a few other key players (Campling 2016: 9). Thereby, supermarkets take advantage of their oligopolistic power by exerting pressure upstream the supply chains, leading to reduced prices and lowered process standards. This in turn results in increased pressure on farmers and fisheries to work harder, further incentivizing the exploitation of both nature and labor. Back-breaking work, pesticide poisoning and accident-prone environments are just a few examples to illustrate the increased pressure on farmworkers and fishermen (Campling 2016: 9; Lawrence and Dixon 2015: 216f.; IP5: 70).

These issues are in particular pressing in *weak governance zones*, where human rights are not protected (IOE et al. 2006: 3) According to the OECD (2005), “weak governance zones are areas where governments are unwilling or unable to carry out their responsibilities.” Yet, companies have the same responsibilities in weak governance zones as they do in developed countries. There is a strong claim that they obey the law and respect the principles of relevant international instruments where national law is absent (IOE et al. 2006: 4). In this sense, I refer to the ongoing Responsible Business Initiative in Switzerland, which would establish liability for Swiss corporations that fail to uphold a standard of social responsibility in their operations abroad, including those in weak governance areas.

Hence, governance can be regarded as a top-down approach because lead firms control the distribution of profits and risks along supply chains. Its counterpart, which is referred to as *upgrading*, is a bottom-up approach and describes how stakeholders can maintain or improve their competitive positions within global value chains (Gereffi and Lee 2012: 25).

Furthermore, Gereffi et al. (2001: 6) distinguish between *product upgrading* and *process upgrading*. The former implies that firms can upgrade their product to gain market access to high value chains. For example, smallholders can improve their competitive position through higher standards by producing organically or fair trade-certified products (Gereffi and Lee 2012: 28). By process upgrading, companies make their production more efficient through superior technology or reorganizing the production systems (Gereffi et al. 2001: 6).

Considering that quality standards are key mechanisms by which buyers govern value chains and consumers are the market driving force, they exert pressure on retailers (Gereffi and Lee 2012: 28). Thus, increased consumer awareness and empowerment create pull factors that may lead to more transparent, sustainable, safe and fair food supply chains (Kamilaris et al. 2019: 647f.; Wust and Gervais 2018: 48).

In this context, it becomes clear how blockchain is embedded within the GVC framework. Since most food supply chains are globalized and buyer-driven, retailers exert the most power by dictating environmental conditions of production and prices upstream the supply chains (Gereffi and Lee 2012: 25, 27). Hence, leading supermarkets have become environmental governors (Havice and Campling 2017: 297). In the end, retailers decide what products and information is available to consumers. By implementing new standards with higher environmental criteria, the reputation of a company or a retailer can be improved, leading to a superior position among competing companies (Bailey et al. 2016: 28). In this sense, integrating blockchain technology in supply chains can be regarded as a strategy to cope with the increasing demand of consumers for more transparency. The concept of product upgrading asserts that blockchain-enabled products will gain value through the technology's functionality to drive more manageable standards, whereby new markets can be enclosed. Finally, blockchain technology improves the efficiency of supply chains, embodying the described upgrading process.

3 Methods

For this master thesis, qualitative methods were applied. Quantitative approaches were unsuitable as they follow a standardized data acquisition with precisely predefined questions and hypotheses (Reuber and Gebhardt 2011: 98). Irrespective of the research and interview context, a standardized data acquisition approach is supposed to lead to the identical results (Helfferich 2011: 154), while intersubjective verifiability is required (Reuber and Gebhardt 2011: 99).

For qualitative methods, on the other hand, subjectivity of the individual respondents is key. Its main goal is to gain more detailed information about the research topic and to understand the differentiated statements and perceptions of the interviewees (Reuber and Gebhardt 2011: 97). Thus, readers can obtain more nuanced insights, which allows them to broaden and revise their point of view regarding the research topic (ibid: 99). At this point, it is important to mention that these statements are not objective and thus do not necessarily represent the objective reality. Instead, they are subjective perceptions that are based on the narrators' experience and can be influenced on the interaction between the interviewee and interviewer (Helfferich 2011: 22). Hence, the acquired data is context-sensitive as the results may vary (ibid: 155). Moreover, a qualitative approach enables a more open research development. During the course of the data acquisition, new questions may come up, which allows a successive development of the research content. Such a constant refinement of knowledge is referred to as the *hermeneutic spiral*, which implies that the questions for subsequent interviews should be accordingly adapted to the newly gained knowledge (Reuber and Gebhardt 2011: 97f.).

Hence, qualitative semi structured expert interviews according to Bogner and Menz (2002) were conducted. The analysis of the interviews sticks to the content-structuring qualitative content analysis of Kuckartz (2018). In what follows, the present chapter describes and justifies the chosen methods that acquired and finally analyzed the data for this thesis.

3.1 Data acquisition

Data was primarily acquired through semi structured expert interviews. In addition, to support and complement the arguments and perceptions of the interviewees, data from external sources, such as academic literature, news articles and reports from key organizations were gathered. Thus, the following section describes the data acquisition of the expert interviews.

3.1.1 Expert interviews

Talking to experts is an efficient method to collect data. This is particularly the case when experts are regarded as *crystallization points* due to their practical insider knowledge, while they represent a multitude of actors (Bogner and Menz 2002: 7). Therefore, key actors in the blockchain-based food industry were chosen.

This brings up the question who can be regarded as an expert and how expert knowledge is defined. Bogner and Menz (2002) intensively discussed this question in their book. According to them, expert knowledge can be categorized into three dimensions. First, the *technical knowledge* describes the theoretical knowledge, whereby an expert has an advantage of knowledge. The second is the *process knowledge* and is based on organizational constellations and interaction routines. This knowledge is ideally acquired through practical experience in a profession. The third dimension is the *interpretative knowledge*, which represents the subjective relevance and perceptions of an expert (Bogner and Menz 2002: 43f.). Thus, an expert possesses knowledge in all three dimensions in a specific field of activity. Furthermore, based on the described expert knowledge, an expert should be authorized to restructure the terms of actions for other actors in the same field of action in a relevant way (ibid: 46).

Elaborating the guidelines for the interviews

For the qualitative data acquisition, semi structured expert interviews were conducted. Thus, guidelines were established to structure the course of conversation. Open questions were prepared and predetermined reply choices for the interviewees were avoided. This method enables a non-suggestive interview atmosphere as one-word answers are avoided, thereby allowing an open and dynamic conversation (Pfaffenbach 2011: 160).

Based on the previous study of theories and other scientific literature, the guidelines were carefully elaborated (Leitner and Wroblewski 2002: 250). For the development of the guidelines, the four stepped SPSS-criteria by Helfferich (2011: 182–85) were applied. Following the first step outlined in these criteria, a profound brainstorming is conducted through which as many questions as possible were gathered. The next step involved a thorough examination of the gathered questions, through which the number of questions was drastically reduced and structured. Irrelevant questions were eliminated, while overlapping questions were merged to more meaningful questions. Once only the important questions were left, the third step of ordering the questions could begin. This step implies a purposeful grouping of the questions into thematic blocks. I started with an introductory block that consists of simple entry questions designed to make the respondents feel comfortable and to foster an interactive dynamic to the conversation. Thereupon, a block of general questions around the blockchain technology was prepared. A third block with in-depth questions and challenges was grouped, while a last block with respect to the outlook was created. The fourth and last step aims to optimize the phrasing in order to evoke an open narration. An example of an interview guideline can be found in *Appendix 1*.

It is important to mention that these guidelines are not rigid structures. Rather, they serve as a guidance to structure the interview to cover all the desired thematic aspects. If necessary, questions from other blocks can be prioritized. This also includes ad hoc questions and comments to react adequately to the statements. Applying this approach prompted more nuanced discussions and often led to informative and fundamental information. Thus, the interviewer can flexibly react to the responses of the interview partners (Pfaffenbach 2011: 160). An open course of the conversation enables a pleasant interview atmosphere, which in turn facilitates the strived room for the development of the interviewees' perceptions (Kassner and Wassermann 2002: 106).

Depending on the interviewee's background, adjusted guidelines had been elaborated, allowing for specific process and interpretative knowledge to be obtained. Based on the hermeneutic spiral, newly gained insights were considered and incorporated for the upcoming interview guidelines.

Sample of expert interviews

According to Patton's (1990: 169) *purposeful sampling* strategy, information-rich actors with adequate knowledge regarding the research topic were chosen as interview partners. In addition, the *snowball sampling* was applied, which involves asking interviewees whether they can recommend additional relevant interview partners (Patton 1990: 176). This approach was insofar successful as it led me to two additional interviews. Furthermore, Patton's (1990: 172) *maximum variation sampling* was adopted. This strategy is purposeful for small samples and strives for a great deal of heterogeneity. Its aim is to involve actors with different backgrounds in order to represent a great variation of opinions (ibid: 172).

In total, a sampling unit of nine interviews was achieved. *Table 1* lists the interview partners and provides a brief description of their background. Three of the respondents are employed within the academic field, implying that they teach or do research at a Swiss university in the domain of blockchain (IP1; IP3) or responsible agriculture (IP4). These persons can be regarded as experts as they have technical and process knowledge about blockchain technology. Although I contacted 13 retailers and leading food companies, only one representative (IP2) of a Swiss leading retailer agreed to an interview. To my personal surprise, three providers of blockchain-based solutions (IP5; IP6; IP9) for the food industry were willing to give an interview. IP7 is a representative of an international standard organization that develops global intersectoral standards. Hence, this organization acts as a mediator between companies and industries that negotiate and introduce global standards with the aim to improve efficiencies and visibilities across supply chains. Finally, a representative from a global tuna development company (IP8) was interviewed. This organization promotes, develops, and monitors the global supply chain of sustainable tuna with innovative technologies such as blockchain.

Table 1 Background of the expert interviewees

Name in text	Background	Interview setting	Date of interview
IP1	Academic field (university)	Personal meeting	10.03.2020
IP2	Retailer representative (supply chain information solution manager)	Phone call	19.03.2020
IP3	Academic field (university of applied studies)	Phone call	30.03.2020
IP4	Academic field (university)	Zoom video call	08.04.2020
IP5	Provider of blockchain-based solutions	Zoom call	26.03.2020
IP6	Provider of blockchain-based solutions	Skype call	03.04.2020
IP7	Representative of a standard organization	Phone call	23.04.2020
IP8	Tuna industry	Skype call	19.05.2020
IP9	Provider of blockchain-based solutions	Written email	24.06.2020

Some respondents provided sensitive information about their own or competing organizations. For privacy reasons, all the interview partners and their representative organizations are treated anonymously (Kuckartz 2018: 171).

From here on, respondents are referred to as ‘IPX’. The ‘IP’ stands for ‘interview partner’, while the ‘X’ identifies the respondent. The number behind the colon refers to the line number in the transcript, where the statement can be found.

3.1.2 Conducting the interviews

Initially, I planned to conduct most of my interviews with Swiss retailers to understand how blockchain affects their businesses. However, most of them declined my request. They mostly argued that they did not have the human resources due to COVID-19 or other reasons. Therefore, I also contacted retailers and food companies abroad of which I knew they had gained experiences with blockchain. However, none of them were willing to agree to an interview either. Hence, I focused to expand my data samplings to include actors from the blockchain-enabled solutions and from the academic research field.

Contacts to the interviewees were established via email. Due to COVID-19, only the first interview (IP1) was conducted face-to-face in his office, while the rest of the interviews were held over Skype, Zoom or telephone. Since three of the interviewees come from other continents, a reasonable appointed time was a prerequisite. During the conversations, notes were taken for important statements or if spontaneous questions from my side emerged. One respondent (IP9) insisted to reply to my questions in written form via email.

3.1.3 Reflection

Based on the appearance and assessed knowledge of the interviewer, interviewees may perceive the interviewer differently. Thereby, Bogner and Menz (2002: 50-62) describe six types of interviewers: as a co-expert, expert of another science domain, layperson, interviewer with authority, accomplice, or a potential critic. Reflecting these different roles helped me retrieving the desired information. When considering my role during the interviews, I can recognize myself in most of the mentioned roles. For example, it was helpful pretending to be a layperson with little knowledge with the intention to retrieve general and theoretical information. Contrariwise, if the respondent’s expertise was mainly based on operational knowledge in the food industry and with a rather minor expertise in the blockchain domain, I sometimes felt superior and thus as an expert from another scientific field. As described by Bogner and Menz (2002: 59f.) access to confidential information can be enabled, by pretending to be an accomplice. Thereby, I could convince them that we share the same interests regarding the topic. Sometimes this role helped me gaining sensitive information about competitive or other actors along the supply chain. In the beginning of the interviews, I tried to avoid critical questions, which helped me gaining the trust of the respondents. As described by Bogner and Menz (2002: 58), this strategy led to more open and honest dialogues, whereas I normally confronted the respondents with criticism at the end of the conversation. In doing so, I expressed the criticism in a personally exclusionary way, whereby the faced criticism comes from others. Vice versa, I also faced constructive criticism regarding blockchain technology, which evoked new research fields for me.

3.1.4 Interview transcripts

Apart from the interview with IP9, which was conducted in written form, all conversations were recorded after obtaining the approval from each interview partner. These audio recordings allowed me to transcribe all the interviews verbatim, for which I used the MAXQDA's transcription mode. For the transcription, the recommended transcription rules of Kuckartz and Rädiker (2019: 42) were considered. Those rules imply that each speech contribution is transcribed as a separate paragraph. Paragraphs are introduced by bold letters "I" or "B", indicating the speech of the interviewer (I) or the respondent (B). Moreover, dialects were translated as accurately as possible into the standard form, which was the case for four interviews (IP2; IP3; IP4; IP7). Those interviews were translated form Swiss German to standard German. The rest of the interviews were held in English and thus accordingly transcribed. Moreover, language and punctuation were slightly standardized if necessary. Agreeing utterances (mhm, aha, etc.) were left out, unless they were meaningful and thus transcribed as "yes". Furthermore, vocal utterances were noted in simple brackets, e.g., "(laughs)". Incomprehensible words and phrases were indicated by (unclear). Finally, all information that could draw a connection to the interviewee or its organization were marked as "xxx".

The transcripts cannot be published and had been submitted to my supervisor.

3.1.5 Literature analysis

Although blockchain is a relatively new technology, a plethora of news articles and academic journals exists, describing its potential to disrupt existing food supply chain processes. Thus, to answer my research questions and support the arguments, a comprehensive literature analysis was conducted according to Kuckartz (2018). LexisNexis Academic and JSTOR served as proper news aggregators, while only English and German articles were considered. These articles were retrieved as they provide a differentiated view about the current state regarding blockchain within the food industry. Moreover, these sources were used to complement or disprove some statements of the interviewees. In total, 19 articles were collected and analyzed according to the same content-structuring qualitative content analysis suggested by Kuckartz (2018) as for the interviews.

3.2 Data analysis

For both the expert interviews and the literature, the analysis of the data follows the content-structuring qualitative content analysis according to Kuckartz (2018). Thereby, the MAXQDA software was used and was of great help as it allows an easy coding of the data. For the creation of the code system, a combination between a concept-driven (deductive) and a data-driven (inductive) category formation was chosen. For the deductive category framework, the guidelines from the interviews were used (ibid: 72, 97).

In the first step, the data was explored by reading all transcripts and making notes in form of memos to important text passages. In a second step, the main codes were deductively defined as they had been deduced from the research questions and the guidelines of the semi structured interviews. Once the main codes were defined, a test run of two interviews was conducted. Hereby, the main codes were refined and some of the subcodes were established, indicating an inductive establishment of a hierarchical code system (ibid: 101f.). The hierarchical structuring was useful for search processes and for the comparisons of top-level codes as overlaps between subcodes could be examined (Kuckartz 2018: 72, 95; Kuckartz and Rädiker 2019: 95). In a third step, once categories and subcategories had been roughly defined, the first full coding process of the data was conducted. Here, the whole data was analyzed and codes were applied to all the text passages that are of significance for my work (Kuckartz 2018: 102). Between the first and second coding process, the codes and the subcodes needed to be differentiated. Hence, these codes were inductively classified and structured in more detail based on the data (ibid: 108). Attention was paid to the ordering of the main codes as they serve as titles and thus guide the structure of the whole work. For instance, it starts with the basic knowledge around blockchain technology and then continues with its use cases in the food industry, while its opportunities and challenges are addressed later. To keep the manageability of the codes simple, as few subcodes as possible were created, while similar categories were merged (ibid: 85, 118). In a further step, a second coding of the whole data with the differentiated codes was conducted (ibid: 110). Thereby, some text passages were assigned to several codes as they contain ambivalent contents (ibid: 111). In the final step of the analysis, a theme matrix was complied, with a row for each interviewee and columns for the main codes and subcodes. Thereby, all the statements of the interviewees are listed in thematic columns.

A coding tree of the qualitative content analysis with its codes and sub-codes can be found in *Appendix 2*.

4 Blockchain technology fundamentals

This chapter justifies why blockchain can be regarded as an added value for various business cases apart from the financial industry. For this, the architecture, underlying concepts, and key components of blockchain are explained. Furthermore, it is discussed to what extent the hype around blockchain is justified. Finally, various use cases are presented for which blockchain has been implemented.

4.1 Blockchain demystified

Blockchain was introduced by an unknown person or group with the pseudonym Satoshi Nakamoto in 2008. The published white paper titled, “Bitcoin: A Peer-to-Peer Electronic Cash System” laid out the framework for the blockchain technology behind the cryptocurrency Bitcoin (Nakamoto 2008). The term blockchain stems from its technical structure that indicates a chain of blocks (Wust and Gervais 2018: 45). Due to the fact that there is no single universal definition of blockchain (Kakavand et al. 2017: 6; Queiroz, Telles, and Bonilla 2019: 242), there are varying interpretations of blockchains. According to the Cambridge dictionary, “blockchain is a system used to make a digital record of all the occasions a cryptocurrency (= a digital currency such as bitcoin) is bought or sold, and that is constantly growing as more blocks are added.” This definition is clearly linked to its initial financial purposes, while it does not mention any other applications, nor does it explain its distributed characteristic. One formal definition of the blockchain technology is provided by Risius and Spohrer (2017):

> “Blockchain technology refers to a fully distributed system for cryptographically capturing and storing a consistent, immutable, linear event log of transactions between networked actors. This is functionally similar to a distributed ledger that is consensually kept, updated, and validated by the parties involved in all the transactions within a network.” (Risius and Spohrer 2017: 386)

However, several key characteristics of the technology, such as data security and its validation process are still missing in this definition. Finally, Al-Saqaf and Seidler (2017: 339) described the technology in oversimplified terms that lack of detailed content: “the blockchain is a distributed ledger or accounting book”. None of these definitions are fully satisfying because key characteristics are missing that describe the underlying logic of blockchain technology.

In the blockchain literature, the blockchain technology has been concordantly described as a digital, decentralized and distributed ledger that can be used to record transactions in timestamped blocks as they are chronologically ordered (Azzi, Chamoun, and Sokhn 2019: 584; Casino, Dasaklis, and Patsakis 2019: 55; Cole et al. 2019: 470; FAO and ITU 2019: 1f.; Galvez et al. 2018: 222; Kamilaris et al. 2019: 640; Queiroz et al. 2019: 242; Wang, Singgih, et al. 2019: 221). Hereby, decentralization and recording transactions are emphasized, while the term blockchain is a hyponym of the distributed ledger technology (DLT) (Treiblmaier 2018: 547). For the definition of DLT, the FAO and ITU (2019: 11) provides an accurate definition: "A distributed ledger describes a type of database, or system of records, that is shared, replicated and synchronized among all members of a network." In this sense, DLT has become the umbrella term for technologies that store, exchange or distribute data publicly or privately based on shared transaction ledgers (OECD and KPMG 2019: 7). Thus, both technologies, DLT and blockchain technology record information on a distributed network and both enable a higher degree of transparency than traditional centralized databases (Chandler 2019). While some authors use the two terms interchangeably (Al-Saqaf and Seidler 2017: 99; Attaran and Gunasekaran 2019: 1; OECD and KPMG 2019; Wang, Singgih, et al. 2019: 221), each come with its own distinguishing features that are explained in section *4.4*.

Iansiti and Lakhani (2017: 125) as well as Furlonger and Uzureau (2019: 5) suggest basic principles underlying the blockchain technology. Summarized below are the four most important elements of these two works:

1. Distributed database: The ledger is replicated with identical copies of the database and stored on all participating nodes. Each participant on a blockchain has access to the entire database and its complete history. Thereby, no single participant holds full control over the entire database or dictates its rules, which prevents malicious manipulation of the data. Based on the decentralized design of blockchain, participants communicate directly (peer-to-peer) and in real-time with each other, making intermediaries redundant as each participant can verify the records of transactions of their partners.
2. Transparency with pseudonymity: All transactions and its contents are visible for all participating users. Since all transactions are validated and timestamped, users can verify and trace them at any point, enabling an effective auditability. Each user has a unique alphanumeric address that identifies them, allowing users to remain anonymous or show their identities to the others.
3. Immutability of records: Once a transaction is completed and cryptographically stored on the ledger, the records can no longer be modified because they are linked to all previous transactions.

4. Computational logic: Computational algorithms are deployed to ensure that the recordings are immutably stored and available for all other participants. Algorithms and rules can also be programmed to automatically trigger transactions between parties.

As mentioned above, the blockchain consists of a sequence of blocks, while each block contains a list of recorded transactions. *Figure 1* illustrates the architecture of a blockchain. The first block of a blockchain is known as the *genesis* block. Each block is linked to the previous block with a hash value matching to the hash value of the previous block, which is known as the *parent* block. Thereby, a new block is added, while the length of the chain can grow with arbitrary numbers of added blocks. Furthermore, a block consists of a *block header* and a *block body*. The block header contains the information of the parent block hash, *the merkle tree root hash*, a timestamp, the block version, the *nonce* and the *difficulty target*. The merkle tree hash indicates the hash value for all transactions in the block, while a current timestamp in seconds is added. The block version defines the set of rules for the validation of the blocks (Zheng, Xie, H.-N. Dai, et al. 2017a: 355f.), whereas the nonce is a randomly or pseudo-randomly calculated number by miners that needs to be identical with the difficulty target value in order to fulfill the consensus requirements (Lemieux 2016: 121). Once the correct nonce is found, a new block is issued, a process that is referred to as *mining*. A block body simply lists all transactions within a block, while the maximum number of transactions within one block depends on the block size and the size of each transaction (Zheng, Xie, H.-N. Dai, et al. 2017a: 355f.).

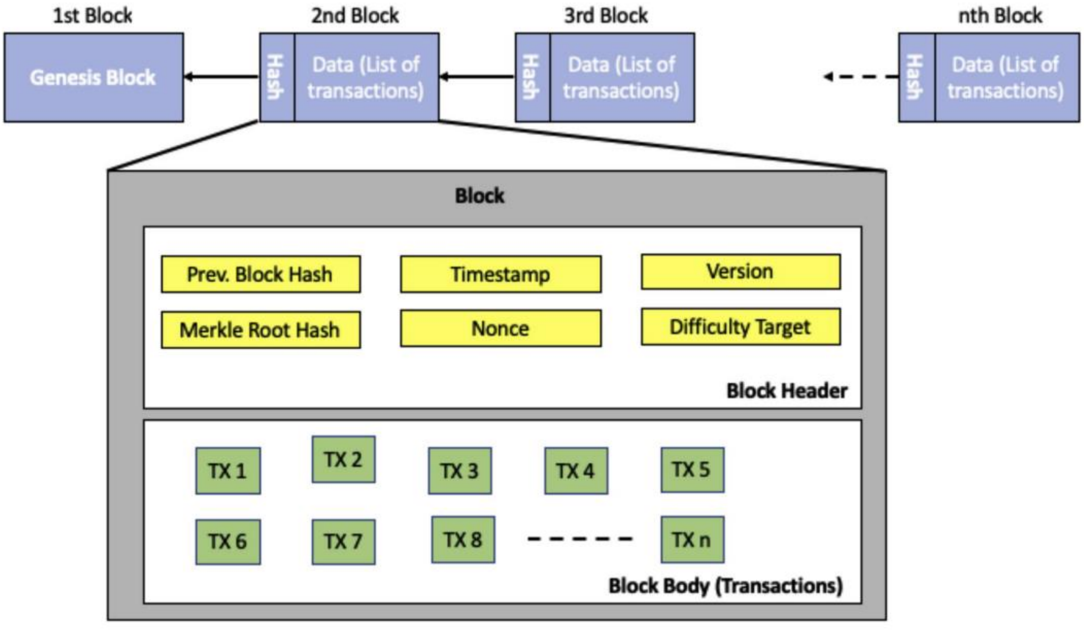

Figure 1Illustration of the architecture of a blockchain containing n blocks (Kamilaris et al. 2019: 641)

4.2 Why blockchain?

In typical transactional relationship, multiple parties are involved and each of them typically has their own version of the truth. Therefore, traditional relationships are prone to errors, duplications and redundancies that may lead to inefficiencies in business processes. A single shared distributed digital ledger alleviates these inefficiencies as the ledger is virtually tamper-proof and allows only a single version of the truth among all involved parties (Yiannas 2018: 49).

Depending on the use case, there are several reasons that favor the implementation of a blockchain. The most evident reason, regardless of its application cases, is the enhanced transparency and trustworthiness. Once a transaction is recorded to the distributed ledger, it cannot be altered or manipulated, and participants can trace every transaction across the blockchain. This feature makes a distributed ledger superior to a traditional centralized database where outsiders cannot assess the trustworthiness of the disclosed information (Galvez et al. 2018: 226). Thus, blockchain offers trust as it enables collaborations between parties without establishing trust between each other. Instead, they only have to trust the blockchain itself, without relying on a trusted third party (Schlegel, Zavolokina, and Schwabe 2018: 3478).

Galvez et al. (2018: 223) elaborated a spider chart (see *Figure 2*) that compares the disadvantages and advantages between a blockchain and a centralized database. While full trustworthiness and enhanced transparency can be enabled, the traceability of blockchain-enabled networks are comparable with traditional centralized databases. They argue that within a blockchain-enabled traceability system, products can be tracked within a few seconds, whereas a well-performing centralized system could achieve similar results. Moreover, the

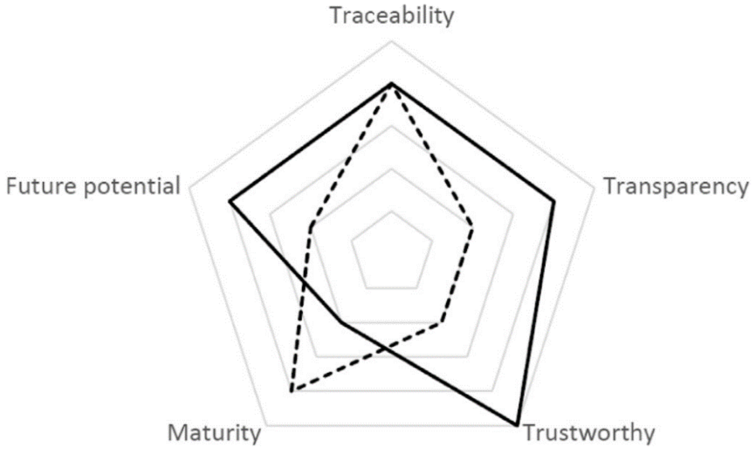

Figure 2 Spider chart of a blockchain (solid line) compared to a centralized database (broken line) (Galvez et al. 2018: 223)

immature and early state of the blockchain technology is depicted, due to its relatively recent emergence in 2008. Therefore, apart from the applications in the financial industry, the experience with such a distributed network has been strongly constricted (Galvez et al. 2018: 223-225). On the other hand, there is an immense future potential around blockchain as it provides a foundational infrastructure for further applications that have not been considered yet (Iansiti and Lakhani: 2017: 120; IP3: 38). The number of possible use cases explode when *smart contracts* in combination with Internet of Things (IoT) are integrated, leading to huge rooms for innovations (Schlegel et al. 2018: 3478). In this sense, blockchain is regarded as a fundamental infrastructure for other emerging technologies, such as AI, drones, 3D printing and biotechnologies, as it connects them and can become a true game-changing technology (Word Economic Forum 2018: 12).

4.3 Smart contracts

The use of smart contracts is a key element to improve efficiencies within blockchain-enabled applications (Casino et al. 2019: 56; Wang, Singgih, et al. 2019: 223). Yet, the concept of smart contracts is older than the blockchain technology and was first introduced by Nick Szabo in 1994. He suggested that the terms of a contract could be transferred with a computerized protocol, whereby the need for intermediaries is reduced (Casado-Vara et al. 2018: 394).

The terms of smart contracts are defined in a computer language instead of a legal language. Thus, they are completely digital (Natarajan et al. 2017: 18). Smart contracts are embedded within blocks and can be triggered over a unique address on the blockchain (Kim et al. 2018: 336). On predefined rules and policies, parties can reach agreement on a transaction without a trusted third party and any human intervention, leading to a high level of automatization and thus smart contracts can substantially modernize existing business cases (Casado-Vara et al. 2018: 394; Wust and Gervais 2018: 51). Once the contractual terms have been met among two parties, a transaction is automatically executed. The potential applications for smart contracts seem limitless (Hughes et al. 2019: 276). This is in particular the case when IoT and/or AI is integrated, which improve automated transactions (Kshetri 2018: 82). Therefore, smart contracts constitute a significant feature for cost reduction and security enhancement (Queiroz et al. 2019: 249).

Figure 3 illustrates how a smart contract could be ideally deployed in a food supply chain. Producer A offers a product for a certain price and quality via a smart contract on a blockchain.

At the same time, a supermarket B deploys a smart contract looking for the same product, quality and price. When the trade conditions between producer A and the supermarket B match, a contract is automatically triggered, leading to a trade between the two parties without the need of any intermediaries.

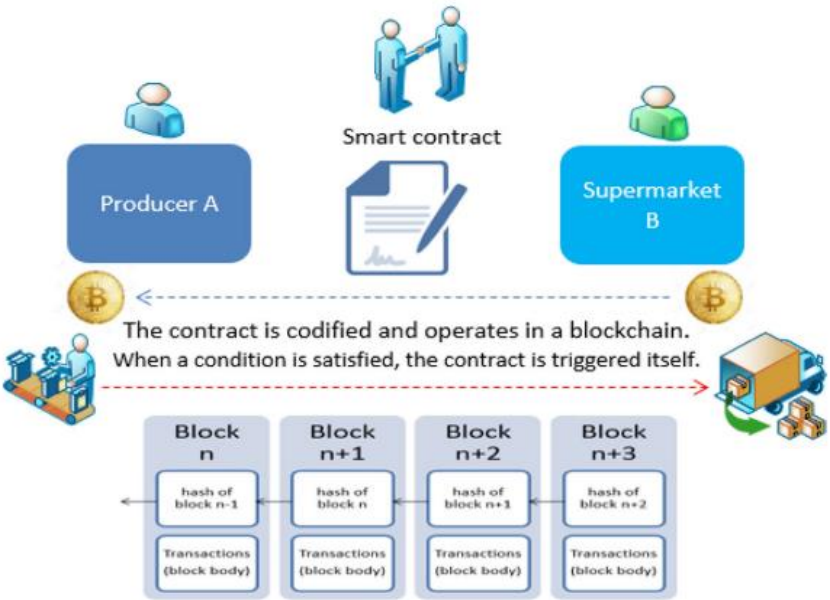

Figure 3 Example of a trade using a smart contract (Queiroz et al. 2019: 243)

Even though smart contract features are currently not available to all blockchains and they are still at an early development stage, they are developing fast (Wang, Han, et al. 2019: 74; Zheng, Xie, H.-N. Dai, et al. 2017a: 371). Due to the technology's infancy, the risks and benefits posed by smart contracts are mostly theoretical and we are still far away from widespread practical deployments (Natarajan et al. 2017: 18). Therefore, it is not yet clear to what extent smart contracts are legally binding and how they should be interpreted (Wust and Gervais 2018: 52).

4.4 Three main types of blockchains

There are several ways to categorize blockchains (Casino et al. 2019: 56f.; Cole et al. 2019: 471; OECD and KPMG 2019: 9; Tian 2018: 161; Wang, Singgih, et al. 2019: 222; Wust and Gervais 2018: 45–47). Based on the network's management and permission structure, blockchains can be roughly categorized into *public*, *private* and *consortium* blockchains (Zheng, Xie, H. Dai, et al. 2017b: 559).

The main difference between public and private blockchains lies in its membership policy that determines who gets access to participate in the network (Cole et al. 2019: 471). A public blockchain is open for anyone to join, while membership must be granted before participating in a private blockchains (Zheng, Xie, H. Dai, et al. 2017b: 559). Consortium blockchain are considered as a hybrid form as they possess a combination of public and private network characteristics (Tayeb and Lago 2018: 36f.).

In general, public distributed ledgers are *permissionless*, which indicates that they are open for any writers and readers to join at any time. In this case, there is no centralized authority and no participant has more power than the rest of the network (Sankar, Sindhu, and Sethumadhavan 2017: 8). Most cryptocurrencies, like Bitcoin, Ethereum and Litecoin are public permissionless blockchains that are open for anyone to join as a new user or node miner (Casino et al. 2019: 57). One main advantage of this type of ledger lies in the high level of trust (IP1: 51). Given that data is stored on a large number of nodes, it is nearly impossible to tamper transactions in a public network. On the other hand, the transaction process takes longer due to its large number of participants, while the data throughput is limited and the latency is high (Zheng, Xie, H. Dai, et al. 2017b: 559).

There is also the variation of public *permissioned* blockchains where permission is required to write on the blockchain, but no authorization is needed to read data. This feature makes the public permissioned blockchain appealing for the public sector and for supply chain ledgers where only specific entities are approved to alter the data, while everyone can view the registers (IP1: 31; OECD and KPMG 2019: 8f.;). For example, consumers at a supermarket are granted access to trace the stages of a product’s supply chain, but they cannot change data on the blockchain.

Furthermore, there are private blockchains. The term private implies that these types of blockchain are permissioned since they require an invitation to join the network, while the verification process may be performed by only pre-selected nodes (Attaran and Gunasekaran 2019: 16). Permissioned networks assume a higher trust level as the consensus finding is based on pre-determined nodes (Stiller et al. 2019: 66). They offer faster transaction speeds and a higher degree of privacy compared to public networks (Attaran and Gunasekaran 2019: 16).

In addition, to be more precise, there is the variation of fully private blockchains where a single organization holds full control over decision makings and the validation processes (Casino et al. 2019: 57). Here, all participants are authenticated and their identity is known to all other nodes (Azzi et al. 2019: 584). Due to its centralized structure, fully private blockchains are regarded as centralized networks (Zheng, Xie, H. Dai, et al. 2017b: 559), which contradicts the nature of the decentralized design of blockchains (OECD and KPMG 2019: 8). This makes fully private blockchains vulnerable to tampering since a single point of failure in the network is created that manages the entire database (Zheng, Xie, H. Dai, et al. 2017b: 559). Therefore, fully private blockchains are often not considered as genuine blockchains as they share similar characteristics with a traditional centralized database (OECD and KPMG 2019: 8). This brings up the question whether a private blockchain is better suited than a traditional centralized database (IP3: 28-30; Wust and Gervais 2018: 45).

Finally, there is the variation of a consortium blockchain, also referred to as federated blockchains (Casino et al. 2019: 57). The term consortium indicates that any group of companies or organizations work toward a common goal that they cannot achieve individually on their own (Furlonger and Uzureau 2019: 47). Within a consortium blockchain, a set of pre-selected companies are involved in the decision making processes (OECD and KPMG 2019: 8). They share similar privacy protection levels as private distributed ledgers and are permissioned as well. The main difference is that within consortium blockchains, a set of several nodes, named leader nodes, are authorized to verify the transactions and grant permissions to new users (Casino et al. 2019: 57). In consortium blockchains, not every participant has equal rights since only selected participants are given privileges to validate transactions, while the rest may validate, but the selected members must reach consensus (Sankar, Sindhu, and Sethumadhavan 2017: 8). Hence, consortium blockchains are partially centralized, while they are more efficient than public blockchains in terms of data throughput and latency (IP1: 81; Zheng, Xie, H. Dai, et al. 2017b: 559). In the best blockchain case with the highest rates of transaction validations, it is almost as good as a traditional centralized database (IP1: 45). This makes consortium blockchains and thus permissioned the most chosen type for enterprise blockchain solutions (Furlonger and Uzureau 2019: 47).

Table 2 summarizes the most important characteristics of the three different blockchain types and compares them with a central database. The various consensus mechanisms are discussed in the following section.

Table 2 Comparisons of the three different blockchain types with a central database. Own illustration, based on Zheng, Xie, H. Dai, et al. (2017b: 559) and Wust and Gervais (2018: 48)

Property	**Public Blockchain**	**Private Blockchain**	**Consortium Blockchain**	**Central Database**
Throughput	Low	High	High	Very high
Latency	Slow	Medium	Medium	Fast
Read permission	Public	Public or restricted	Public or restricted	Restricted
Immutability	Nearly tamper-proof	Could be tampered	Could be tampered	Could be tampered
Consensus determination	All miners	One organization	Selected set of nodes	None
Consensus mechanism	Mainly PoW, some PoS	BFT protocols	BFT protocols	None
Centralized	No	Yes	Partially	Yes

To finally clarify the terms describing blockchain technology, private blockchains are sometimes also referred to as distributed ledgers, while public blockchains are simply called blockchains (IP1: 29). For the sake of convenience, this work uses the term blockchain for all the above mentioned varieties of DLTs since most scholars use the term blockchain for any type of distributed ledger as well (Casino et al. 2019; FAO and ITU 2019; Iansiti and Lakhani 2017; Kamilaris et al. 2019; OECD and KPMG 2019; Tayeb and Lago 2018; Wang, Singgih, et al. 2019; Wust and Gervais 2018; Zheng, Xie, H. Dai, et al. 2017a). Regardless of the classification of the blockchain type, permissioned blockchains are of particular interest for non-financial business cases as they offer enhanced privacy (Casino et al. 2019: 57; Cole et al. 2019: 471; IP1: 31 Wang, Singgih, et al. 2019: 223). As mentioned above, choosing the right type of blockchain and whether the implementation of blockchain is actually advisable, depends on several factors. In many cases, a much simpler digital solution may be more appropriate (FAO and ITU 2019: 7). Wust and Gervais (2018) discuss these questions in their article and created a decision tree, which I slightly adapted (see *Figure 4*), for choosing the appropriate blockchain type.

A blockchain only makes sense, when data needs to be immutably stored and multiple parties want to write on a shared ledger. If some or all writers in the network are unknown, a public permissionless blockchain is suitable. However, if all writers are known and can be trusted, no blockchain is needed and a traditional database is better suited because it offers better performance in terms of latency and throughput. Then there is the question of whether public verifiability is required. If public verifiability is required a public permissioned blockchain is suggested. Thereby, participants who cannot be trusted can read and verify the data, but they cannot alter the ledger. For instance, this is the case when supply chains of certain products are made visible for end consumers. Then there is the consortium blockchain that is suitable for business cases, where participants of the network can be trusted, but no public verifiability is required (Wust and Gervais 2018: 46f.). Since I am also convinced that fully private blockchain contradict its underlying logic, I omit the option of choosing this type of blockchain and advise those companies to deploy a traditional centralized database instead.

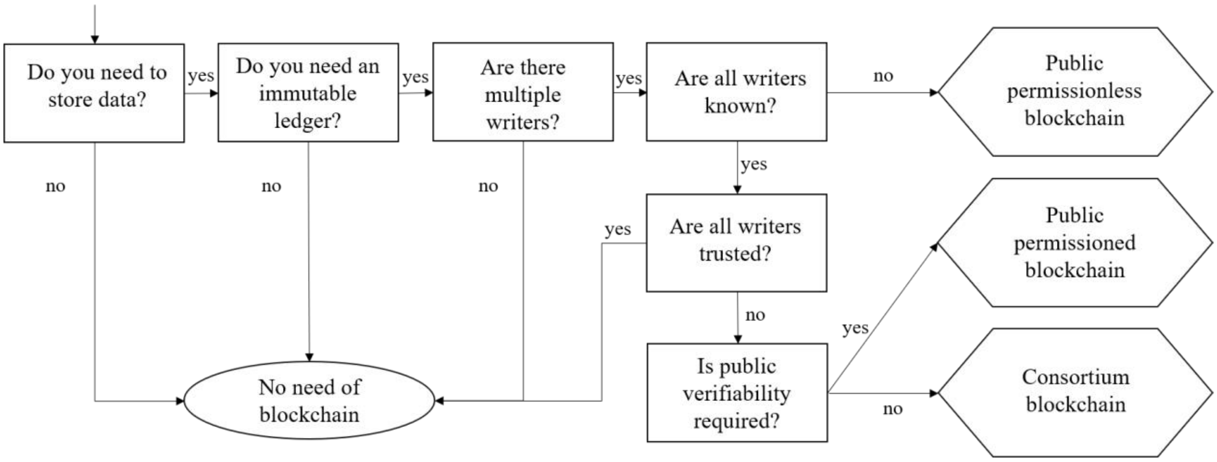

Figure 4 Decision tree for choosing the right type of blockchain. Own illustration, based on Wust and Gervais (2018: 47)

4.5 Consensus mechanisms

Within the blockchain domain, a consensus represents an agreement that authenticates and validates transactions in a decentralized network. It not only ensures that all nodes share the same data, it also prevents malicious actors from manipulating the data (Azzi et al. 2019: 584). Therefore, the consensus mechanism plays a key role in the validation process when new data is added to the blockchain, thus underpinning trust in the data (Pearson et al. 2019: 146).

In a public blockchain, each node in a network could take part in the consensus process. In a consortium blockchain, on the other hand, only selected nodes validate blocks, while one organization controls the validation process in a private blockchain (Zheng, Xie, H. Dai, et al. 2017b: 559). Currently, the Blockchain Consensus Encyclopedia (2020) lists 84 different consensus protocols, which illustrates the plethora of consensus mechanisms within DLTs. Understanding all these mechanisms is a difficult endeavor. Zheng et al. (2017b) and Bano et al. (2017) studied the most common mechanisms and explain their mode of operation. Depending on the blockchain type, a certain mechanism is advocated (De Angelis et al. 2018: 3).

The most well-known is the *Proof-of-Work* (PoW) that is used in Bitcoins and in most permissionless blockchains. PoW requires computer nodes, to solve difficult computationally intensive mathematical tasks. The node that solves the puzzle wins a reward with newly mined coins. Thus, this process is known as mining (Kamilaris et al. 2019: 640). Other nodes verify that the solution and the history of the proposed individual block was not used for previous transactions. If the majority of the nodes reach a consensus, the transaction is accepted and a new block is added to the blockchain (Wang, Singgih, et al. 2019: 222). However, the PoW mechanism requires high computational power to solve the complex tasks and therefore criticism arises regarding the environmental costs of operating blockchains with PoW (Queiroz et al. 2019: 251). Since PoW is an expensive way to reach consensus and all participants need to be authenticated in a permissioned blockchain, this algorithm is usually applied in permissionless networks (Azzi et al. 2019: 584).

Alternatively, there is *Proof-of-Stake* (PoS) that has recently been gaining momentum because it requires significantly less power consumption and its scalability is improved. Thus, many blockchains, such as Ethereum, are gradually shifting to the PoS algorithm (Casino et al. 2019: 57). In PoS, the nodes are known as the validators and no actual mining is done as all coins already exist from day one. The validators do not receive a reward, instead they collect network fees. Simply put, PoS randomly selects nodes to validate the new blocks, while the probability of randomness depends on the amount of stake held by the nodes (Kamilaris et al. 2019: 640). This in turn implicates the drawback that the rich are getting richer as nodes with more digital assets at stake can forge the next node (FAO and ITU 2019: 3).

The *Delegated Proof-of-Stake* (DPOS) is built on the PoS with a slightly different approach to validate new blocks. In DPOS, delegators are elected by all participants of the network to generate and validate blocks (Zheng, Xie, H. Dai, et al. 2017b: 560).

Furthermore, there are byzantine fault tolerance (BFT) mechanisms, while the *Practical byzantine fault tolerance* (PBFT) is the most common concept. The PBFT rests on three rounds of message exchange before it reaches consensus and a new block is added. Here, a node is selected based on predefined rules and this node is responsible to order the transaction. Each round can be divided into three phases, while in each phase a node receives votes from over 2/3 of all nodes. Thus, PBFT can handle up to 1/3 of malicious participants in the network. Since there is no mining in the process, it makes the PBFT a low-consuming energy algorithm as well.

Moreover, when using PBFT, all nodes in the network must be known, which makes it a suitable consensus algorithm for permissioned blockchains (Zheng, Xie, H. Dai, et al. 2017b: 560–61).

The concept of *Proof-of-Authority* (PoA) also belongs to the BFT algorithms (De Angelis et al. 2018: 2). PoA is proposed to be implemented in private networks where participants are authorized and know each other (IP3: 26). PoA tries to overcome the limitations of PoW and PoS by combining those two. Here, the system is run by a certain number of trusted nodes that have the authority to verify new transactions and issue new blocks to the network (Angrish et al. 2018: 1184). Hence, PBFT and PoA are consensus mechanisms that are of particular interest for permissioned blockchains since they are mostly deployed for commercial purposes. De Angelis et al. (2018) advocate, however, that PBFT is a better choice than PoA because consistency is better ensured and data integrity is guaranteed. Therefore, Hyperledger Fabric utilizes PBFT to reach consensus for their permissioned blockchains. *Table 3* summarizes the most important consensus mechanisms.

Table 3 Summary of most important consensus mechanisms. Own illustration, based on Zheng, Xie, H. Dai, et al. (2017b: 560) and Angrish et al. (2018: 1184)

Property	**PoW**	**PoS**	**PBFT**	**PoA**
Node identity management	Open	Open	Permissioned	Permissioned
Energy saving	No	Partial	Yes	Yes
Tolerated adversary power	< 25%	< 51 %	< 33.3%	<50%

4.6 A disruptive technology just akin to the internet?

A disruptive technology describes a new technology that presents the opportunity for value-added transformation, but still lacks refinement, is known only to a limited public, and does not yet have any proven practical applications. In this context, disruption means that existing elements of society may be altered or destructed. Hence, disruptive technologies can potentially change traditional business models and the global economy (FAO 2018b: 178). There are several scholars that perceive blockchain technology as a technical revolution because it has the potential to disrupt traditional businesses (Attaran and Gunasekaran 2019: 17; Casino et al. 2019: 66; Deloitte 2019: 17; Hughes et al. 2019: 274; Iansiti and Lakhani 2017: 120; Queiroz et al. 2019: 243; Schlegel et al. 2018: 3477; Treiblmaier 2018: 556).

Iansiti and Lakhani (2017: 120) do not regard blockchain as a disruptive technology yet. They rather see it as a foundational technology that has the potential to create new foundations for our economic and social systems. They believe that it will take decades until such a disruption will happen and that the process will be gradual and steady. Moreover, they compare the adoption of blockchain technology with the adoption of TCP/IP (transmission control protocol/internet protocol) that laid the groundwork for the development of the internet. After its first introduction at the U.S. Department of Defense in 1972, it took more than 15 years until leading companies, such as Hewlett-Packard, Sun and Silicon Graphics, gradually replaced their traditional local networks with TCP/IP. With the advent of the World Wide Web in the mid-1990s, this technology gained vast attention for the public use. Thereupon, new technology companies rapidly emerged. Once this basic infrastructure gained critical mass, a new generation of companies could take advantage of low-cost connectivity that compelled traditional businesses. To name just a few, Amazon offered more books than any bookstore, while Expedia provided an easier purchase of airline tickets with an unprecedented transparency. With the appearance of eBay, Google, Skype etc., the internet fundamentally changed the traditional business models. In the end, it took the technology more than 30 years to reshape the economy and the way information is shared (ibid: 120).

There are several scholars that see parallels between the blockchain technology and the revolutionary internet in their studies (Galvez et al. 2018: 229; Hughes et al. 2019: 274; Kshetri 2018: 81; Treiblmaier 2018: 545; Wang, Han, et al. 2019: 76). It comes as a little surprise that three interviewees compared the emergence of the internet with blockchain as well (IP1; IP5; IP6). IP5 (92) is convinced that blockchain is currently at the stage where the internet was in 1996, when people were not shopping online, doing video calls, and barely sent emails. According to him, we have not considered yet all the applications around blockchain and the way it will change the world. Just alike in 1996, when we did not see what the internet was going to become.

4.7 Revolution or hype?

Several studies aimed to assess the potential impact of blockchain and how leading companies perceive the technology. For instance, there is Deloitte’s 2019 Global Blockchain Survey that questioned 1’386 senior executives of leading companies how they perceive and assess the emerging technology. According to this survey, 53 percent of the respondents say that the technology has become a critical priority for their organizations. In contrast, only 40 percent responded accordingly in 2018, suggesting that blockchain gained importance in real-world applications. Moreover, the overall attitudes toward the technology have strengthened as 83 percent of the respondents see compelling use cases for the technology compared to 74 percent in the previous year (Deloitte 2019: 3f.). Notably, 35 percent of the respondents had already participated in a blockchain-based project, while 31 percent intended to do so in the next 12 months. An additional 15 percent were leading such an initiative at this stage (Deloitte 2019: 27). In addition, 77 percent (instead of 68 percent in 2018) of the entrepreneurs believe that they will lose a competitive advantage if they do not adopt blockchain technology, implying the concern of being left behind if their company will not adapt to this emerging technology. On the other hand, skepticism has slightly increased as 43 percent see blockchain as overhyped compared to 39 percent in 2018 (ibid: 40).

Gartner, a world-wide leading research and advisory company, conducted a similar survey. Their 2019 CIO Agenda questioned 2’871 chief information officers (CIOs), which states that only three percent of the respondents had a live and operational blockchain, while an additional eight percent were in short-term planning or about to execute a pilot (Furlonger and Uzureau 2019: 13). Another 39 percent plan to integrate blockchain in the next three years (Furlonger and Kandaswamy 2019: 4). In addition, only five percent rank it as a game changer for their organization (as cited in Pemberton Levy 2019).

These blockchain-related participation results presented by Gartner may deviate to the before mentioned study of Deloitte. However, they give a hint to what extent blockchain technology has been realized and what its future may look like. The fact is that companies around the world invest in this technology as they see potential benefits. Hence, blockchains should not just be considered as a hype (Casino et al. 2019: 56). Gartner estimates that blockchain could generate about US$ 3.1 trillion in new business value by 2030 (Furlonger and Uzureau 2019: 3). According to David Furlonger, a Vice President analyst at Gartner, “blockchain technologies are extremely hyped […] but should not be ignored” (as cited in Treiblmaier 2018: 554). On the other hand, Fritz Brugger (2019), a senior scientist at the Center for Development and Cooperation at ETH Zurich, remains cautious regarding the hype around the emerging technology: “Today, blockchain is close to the peak of the hype cycle of technologies with inflated expectations. Riding this wave helps to attract publicity and (donor) funding. But not necessarily to solve every problem at hand.” Thereby, Brugger is addressing the hype cycle for blockchain technologies by Gartner (see *Figure 5*). According to the hype cycle, the blockchain technology is currently sliding into the “Trough of Disillusionment” or elsewhere referred to as the “blockchain winter” (Furlonger and Uzureau 2019: 10), indicating that blockchain has failed to meet the high expectations. After the Through of Disillusionment, the “Plateau of Productivity” begins or as Furlonger and Uzureau (2019: 10) put it: “after winter, spring comes.” Gartner predicted that it would climb out of this valley by 2021, as the technology will mature, and pragmatic use cases will be developed. They conclude that blockchain is not yet a business revolution and will not become one by 2028, when blockchain is expected to become fully scalable, both technically and operationally (Gartner 2019). Furthermore, the hype cycle by Gartner illustrates the expected high potential of the blockchain coupled with IoT or smart contracts as they are still in the “Innovation Trigger” stage, respectively on the “Peak of Inflated Expectations” stage.

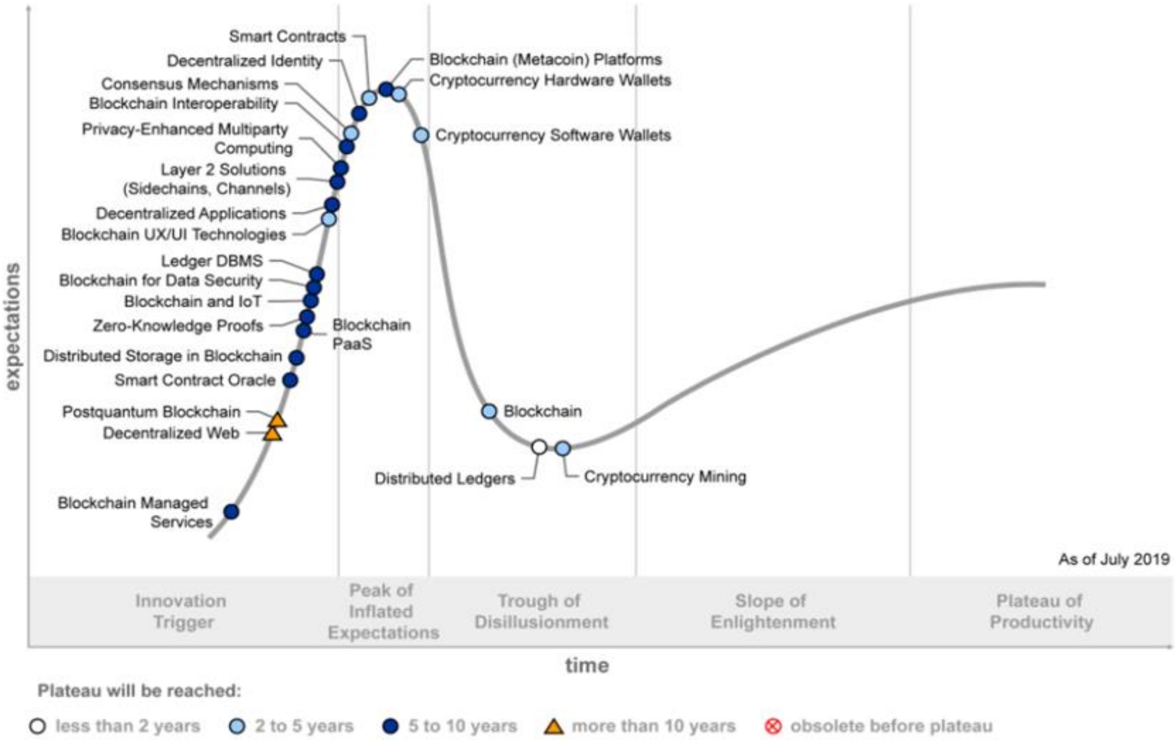

Figure 5 Hype cycle for blockchain technology (Gartner 2019)

4.8 Current applications of blockchain technology

Since 2014, blockchain has been increasingly deployed in further industries apart from cryptocurrencies and other financial use cases (Kamilaris et al. 2019: 641). Apart from financial applications, Bünger (2017) sees the highest potential for applicability of blockchain in the power sector and the food and agriculture sector. These industrial use cases are expected to be among the first where blockchain begins to deliver a real return on investment (ROI). Similarly, Queiroz et al. (2019: 250) believe that the electric power industry, intelligent transportation systems and healthcare systems represents the highest potential for blockchain deployments. The blockchain's immutability characteristic makes the technology suitable for a variety of use cases where a tamper-proof record keeping is desired. Casino et al. (2019: 62) provide a mind map abstraction (see *Figure 6*) of the different blockchain applications. Some of these use cases are explained in the following sections.

Figure 6 Mind map of different blockchain applications (Casino et al. 2019: 62)

4.8.1 Use cases in supply chains

Blockchain has been deployed in several different industries within supply chains. In the pharmaceutical industry, medicine can be traced along the supply chain throughout their lifecycle – from manufacturing to the patients. This mitigates counterfeiting drugs and assists recalls. Moreover, with the use of IoT devices, storing conditions can be monitored more easily (Kehoe et al. 2017: 7f.). If deviations in temperature or other conditions occur integrated smart contracts compare the data against various regulatory requirements and report these findings automatically in case of disaccord. Modum, a Swiss start-up, teamed with the University of Zurich and conducted a pilot project containing smart contracts in 2016 for pharmaceutical drugs (IP1: 87; Kshetri 2018: 84).

The world's biggest shipping company Maersk partnered with IBM and successfully tested a permissioned blockchain platform, called TradeLense, to digitize their supply chain processes in 2017 (Miller 2019; Groenfeldt 2017). For Maersk, the main reason to digitize their processes was the extreme inefficiency of their traditional processes as they rely on piles of paper (Groenfeldt 2017). Digitizing documents shows its advantages when customs authorities, tax officials and health authorities are involved. They can immediately upload a copy with a digital signature. If disputes around the documents occur later all parties can track back the record and ensure themselves that no one had altered the records at any point (Kshetri 2018: 83). This is a great improvement for Maersk as up to 30 parties can be involved for a shipment of refrigerated goods (Groenfeldt 2017). Moreover, goods inside the container may perish, putting a time pressure on its dispatch (Kshetri 2018: 83). Therefore, Maersk gradually expands TradeLense to include further major shipping companies, such as CMA, CGM and MSC Mediterranean Shipping Company, encompassing now almost half of the world's cargo container shipments (Miller 2019).

In the electric power industry, smart contracts are deployed within blockchains that automatically regulate the distribution of power between producers and consumers (Queiroz et al. 2019: 249). Such an example can be found in Brooklyn, New York, where neighbors buy and sell energy from each other in microtransactions using blockchain technology (Attaran and Gunasekaran 2019: 92)

Another interesting use case where blockchain enhances the transparency of supply chains is the mining industry. The provenance of gemstones, such as diamonds, is contested as they are often mined under precarious conditions for laborers in African war zones. Hence, they are sometimes referred to as *blood diamonds*, indicating its unethical sourcing, while funding armed rebel movements at the same time (Baker 2018). Due to these concerns, customers increasingly demand to know where their gemstones come from (IP6: 38). Everledger, a technology start up, aims to solve these issues by providing a blockchain-based solution, called Tracr (Ricadela 2019). Tracr provides a shared and tamper-proof ledger of the stones to fully trace back gemstones to its origin since 2018. By scanning a diamond and adding several metadata points of the stone, a unique thumbprint of the diamond is created and stored on the blockchain (Horch 2020). A similar project called Provenance Proof Blockchain was launched by Gübelin, a Swiss jewelry company, in collaboration with Everledger. Here, DNA-based, nano-sized particles are used to encode the stone's information. This project is in the operating phase as well (Everledger n.d.; IP3: 39-40.). The maturity of Everledger is notably impressive as it has traced over two million diamonds since its establishment (Wang, Han, et al. 2019: 68).

The food industry constitutes a further interesting field for blockchain-enabled traceability systems. Most leading food companies, such as Nestlé, Kroger, Walmart, Carrefour, Unilever, Dole Food, Golden State Foods, but also Migros recognized the potential and have invested in blockchain technology for a better monitoring of their supply chains (Banker 2018; IP6: 44; Jostock 2019: 8; Kamilaris et al. 2019: 643). These use cases will be discussed in more detail in section *5.2*.

4.8.2 Health and governmental sector

There is a great variety of applications for the governmental sector as well. For instance, healthcare systems can be improved by giving access to the needed data to all involved parties, while keeping patient records private and secure (Schlegel et al. 2018: 3482). The government of Estonia uses blockchain for healthcare on a national level to ensure the integrity of health records (Romano and Schmid 2017: 7).

In addition, Estonia offers most of its government services online via digital ID cards that are secured by blockchain. This enables the effortless movement of information between the different government institutions (Garrod 2019: 611). Using their ID cards, citizens can vote, bank online, apply for state benefits, file their tax return and fulfill more functions (Natarajan et al. 2017: 83). The storing of individual citizens' details in blockchains could guarantee that voting is lawful as the potential for vote tampering can be mitigated (Hughes et al. 2019: 277).

According to Cole et al. (2019: 471), the verification of identities can be enabled for vote counting, which substantially fosters democratic processes.

Another typical blockchain application in public services is the land registration. Land tenures in developing countries have long been insecure for citizens due to corruption or loss or irretrievability of the records. For these reasons, Honduras conducted a pilot project using blockchain to digitize land rights. Thereby, landowners are ensured to own rightful land titles (Lemieux 2016: 110). Besides, any transfers of land or the establishment of a mortgage can be recorded on blockchains (Zheng, Xie, H.-N. Dai, et al. 2017a: 365).

4.8.3 Further use cases

Another area where blockchain can be effective is the gaming industry. Here, blockchain technology enables gamers to have ownership of their virtual games and exchange these with other players. This is facilitated by an encrypted ledger of virtual assets that makes duplicating and hacking keys impossible. Furthermore, blockchain provides a safe environment for players to purchase games faster without the need of credit or debit cards (Attaran and Gunasekaran 2019: 86).

A similar approach can be found in the media sector where intellectual property rights and payments to artists can be tracked. This allows a record of ownerships for artists' works (Queiroz et al. 2019: 471).

5 Blockchain in food supply chains

The present chapter introduces the results from my data acquisition and provides answers to the research questions. First, it is justified why the current SCM should be improved. Second, the two main use cases of blockchain in food supply chains are described and it is explained how the technology is integrated. Third, its suitability for certain types of commodities is discussed, while a list of various food products is provided for which blockchain has been integrated. In a next step, its potential benefits and challenges are presented. Furthermore, potential transformations in food supply chains facilitated by blockchain are presented. Finally, the two main use cases are compared and assessed, while an outlook is provided at the end of this chapter.

5.1 Why existing SCMs should be improved

There is common agreement among several scholars that there is a strong need to improve existing SCMs in the food industry (Azzi et al. 2019: 583; Cole et al. 2019: 469; FAO 2018a: 19; IP5: 14; Wognum et al. 2011: 73f.; Wust and Gervais 2018: 48). As Gereffi and Lee (2012: 24) put it: “from a management perspective, there are always issues connected with the efficient and timely distribution of goods that flow across supply chains.“ Current enterprise resource planning (ERP) technology faces limits in SCM due to its centralized structure. This is particularly the case in terms of transparency, flexibility, data accessibility and advanced decision making. Moreover, centralized databases rely on a single entity that controls the data. If this entity fails or shuts down abruptly, the whole system will crash, and production comes to a halt. In China, for example, there is a loss ratio of up to 30 percent yearly due to centralized logistic systems (Azzi et al. 2019: 585), indicating that centralized platforms often inefficiently gather data along supply chains (Wang, Han, et al. 2019: 71).

Due to market globalization and increasing product proliferation, food supply chains are becoming increasingly complex and dynamic (Trienekens et al. 2012: 55). Moreover, information asymmetries exist in the current food supply chain, making some supply chains opaque and difficult to understand not only for end consumers, but also for other stakeholders along the supply chains (Kim et al. 2018: 335). Furthermore, the decline of local manufacturing has created an information gap between producers and consumers, which is rarely bridged by press reports (Provenance 2016). However, there is an increasing demand by disconnected consumers who are concerned about sustainability issues and food safety (Aung and Chang

2014: 182; Trienekens et al. 2012: 59; Wang, Han, et al. 2019: 71). In agriculture, the degradation of land, soil and water is a crucial problem (Kamilaris et al. 2019: 645). In aquatic ecosystems, fish stocks are at high risk and are classified as overfished (FAO 2018b: 45). In addition, 75 percent of the fish species with commercial value have been overexploited (UNEP 2009: 51). Thus, the fishing industry faces enormous challenges due to illegal, unreported and unregulated fishing (IUU), which poses the greatest threat to marine wildlife (FAO and ITU 2019: 9). It is estimated that 20 percent of the global fish originates from IUU fishing, which represents an estimated value of up to US$ 23 billion annually (Agnew et al. 2009: 1f.) In addition, about 14 percent of the food produced for human consumption is lost or wasted along the food supply chain, excluding the retail level (FAO 2019: 22). Furthermore, human right violations occur in fisheries and in the agriculture across the globe (Cook 2018: 5). Finally, there is also the problem around unfair pricing due to the asymmetric power relations between big companies and smallholder farmers, which fosters inequalities (Kamilaris et al. 2019: 647). In order to balance asymmetric power relations, more transparent supply chains are required.

Moreover, there are concerns regarding food safety. According to the WHO (2015), foodborne diseases caused 420,000 deaths in 2010. To name an example of a food integrity case, romaine lettuce contaminated with E. coli bacteria was sold in US stores in 2018. It left 210 people ill and five deaths were reported due to its consumption (Banker 2018).

Furthermore, there is the problem of trust related issues among supply chain participants. For instance, there is the risk of food fraud, which includes mislabeling, substitution, counterfeiting, misbranding and the dilution of food products (FAO 2018b: 154). The European Parliament (2013) published a report on the food crisis, which lists ten products that are most at risk of food fraud. Accordingly, organic foods are ranked third after fish and olive oil. They conclude that the risk of food fraud is highest when the chance of getting caught is small and the potential economic gain is big. Thereby, food fraud is typically realized with intentional mislabeling that includes the substitution of species and adulterating its geographical origin in order to hide illicit practices (FAO 2018b: 154). A well-known case of food fraud is the horsemeat scandal in 2013. Findus, a frozen food brand, experienced a PR nightmare, when their beef lasagna products contained horsemeat up to 100 percent (Neville 2013). Due to such negative publicity, companies can suffer a severe reputation loss and thus experience reduced sales (Kshetri 2018: 80). This is in particular the case in times of social media as consumers can put high pressure on food companies by posting pictures of defective products (Jostock 2019: 10).

Establishing an improved traceability system is not only interesting from a consumers' perspective, but also from a retailers' and food companies' perspective. Van Der Vorst (2006: 34) identified three major traceability strategies for food companies: compliance (complying with governmental regulations), process improvement, and branding (creating added value in the market).

There is a wide range of legislative demands that need to comply with food safety regulations. The Code Alimentarius Commission (CAC) was established by the FAO and the WHO and defines food safety standards on a global level (Trienekens et al. 2012: 60). The principles of the traceability are stated in the document CAC/GL 60-2006 and imply:

> "The traceability/product tracing tool should be able to identify at any specified stage of the food chain (from production to distribution) from where the food came (one step back) and to where the food went (one step forward), as appropriate to the objectives of the food inspection and certification system." (CAC 2006: 3)

Even though additional regulations may be added at a domestic level, they normally follow similar requirements as the ones posed by CAC (Charlebois et al. 2014: 1109). In 2005, the EU legislation 178/2002 was implemented. It implies that food business operators are liable for unsafe products (Trienekens et al. 2012: 60). Yet again, they must only provide information about their proximate suppliers and buyers. Non-EU members, such as Switzerland and Norway follow similar requirements to the EU regulations (Charlebois et al. 2014: 1109). This pragmatic one up/one down approach connects all bound actors along a supply chain since each of them knows from whom and to who their products have been supplied. However, this traceability system is vulnerable to quickly needed retracements. It relies on each actor's participation since data is stored in silos, while some food products go through complex supply chains (Pearson et al. 2019: 146). Hence, it becomes clear that supply chains are as strong as its weakest link (Trienekens et al. 2012: 56). Moreover, it soon becomes nearly impossible to trace commodities that have been blended (e.g., milk from multiple farms) or that have been mixed along the supply chain.

In addition, the agriculture sector remains one of the least digitalized industries (FAO and ITU 2019: 31). The food industry still largely relies on paper records that are barely digitized, making the search after a product's provenance time-consuming (Pearson et al. 2019: 146). Currently, real-time tracking is not possible within centralized SCM (IP1: 45; Kehoe et al. 2017:

13). However, time is crucial when it comes to disease outbreaks and unsafe products need to be withdrawn in order to stop the spreading of foodborne illnesses (Wang, Han, et al. 2019: 72). In case of such recall incidents, retailers often remove all articles from their shelves and not just the ones that are directly concerned, leading to greater food waste (Van Der Vorst 2006: 34). In this sense, reducing paperwork and food waste can be regarded as sustainability concerns.

Feeding the ever-growing population poses enormous challenges. Hence, innovation in the food industry is needed to make production processes more efficient. The FAO strives to overcome these challenges by involving smallholders, such as farmers and fishermen, in the food sourcing and production. Therefore, the FAO and the ITU (2019) promote the use of sustainable ICTs in food production, which explicitly involves blockchain technology.

5.2 How blockchain is integrated in food supply chains

According to several authors, the blockchain's immutability characteristic meet the requirement for a tamper-proof record keeping throughout food supply chains, thus enabling full transparency and traceability for all desired stakeholders (Kehoe et al. 2017: 4; Kim et al. 2018: 337; Schlegel et al. 2018: 3484). First of all, it is important to understand how blockchain is integrated into existing food supply chains. Even though there are different reasons why blockchain-enabled tracking is deployed within food supply chains they are generally introduced by food companies with the aim to either offer traceability for their end consumers or to improve their internal supply chain processes.

In the following sections, the two main use cases are briefly introduced, while the setup of a blockchain with its underlying technologies is presented. Finally, a realistic use case of a blockchain-enabled supply chain is illustrated for the commodity of tuna.

5.2.1 End user experience through public verifiability

One main purpose behind deploying blockchain in food supply chains is to enhance the end user experience through public verifiability. This implies that all stages of a supply chain are made visible to end consumers in order to comprehend where, how, and when products had been processed. For enabling such end user experiences, a tag (usually a QR (quick response) code) or a unique lot code must be provided on the food package that uniquely identifies the item (IP3: 6; IP5: 34). By scanning this tag with a mobile phone, consumers can access information about a product's provenance and journey, including locations and timestamps of all stages of its food chain, production methods and food safety information (Galvez et al. 2018: 228; IP6: 54).

For example, Gustav Gerig, a Swiss retailer, teamed up with Atato, a blockchain service provider, to provide information about their canned tuna to end consumers. By scanning a QR code, consumers are directed to their webpage where they can enter the imprinted lot code on top of the lid. Thereby, information about the sourcing and production methods are given to consumers who can make more educated shopping decisions.

By giving access to production information, consumers can take informative decisions that are aligned with their values (IP5: 12). Thereby, retailers can generate customer loyalty and increase trust with transparent record keeping (Galvez et al. 2018: 226).

5.2.2 Internal traceability for process improvements in SCM

Blockchain-based traceability systems are also deployed by leading food companies to improve the performance of their SCM by optimizing the efficiency of internal processes. There is a great variety of application fields and thus its benefits are manifold, which are discussed in detail in section *5.4*. Its main advantages comprise increased trust among business partners, chain transparency, and various efficiency optimizations due to digitalizing processes enabled through blockchain (Stiller et al. 2019: 6). Furthermore, improvements are expected for tamper-proof storage of data, governance, compliance, traceability system, automated verification, automated data collection and the analysis of data (IP2: 6; IP5: 24, 28, 62; Stiller et al. 2019: 9).

To optimize SCM, blockchain can be linked to existing enterprise resource planning (ERP) systems that integrate all major business functions within one system. Connecting these two systems creates synergies with other companies, which enables the full visibility of the flow of goods across supply chains for all involved parties (OECD and KPMG 2019: 7). Due to the decentralized data storage of blockchain, a secure exchange of digital assets and documents is facilitated, without the need of trusting other parties along the supply chain (Wust and Gervais 2018: 51).

For instance, Migros, the largest retailer in Switzerland, deployed a private permissioned blockchain to trace fruits and vegetables along their supply chains. They use it for product recalls in case of contamination, controlling input data of its suppliers, checking availability of its suppliers, food waste reduction and further process optimizations (IP2: 2, 6, 26, 40; TE-FOOD 2019). Walmart deployed a blockchain for tracking diverse food products such as mangoes, strawberries, meat, and dairy products (Hyperledger 2019). Further existing use cases are presented in section *5.3*.

5.2.3 Setting up a blockchain ecosystem

There are several scholars and organizations that provide useful guidelines and advice how a blockchain can be integrated in an existing supply chain (FAO and ITU 2019: 7; Wang, Han, et al. 2019: 78f.; Wust and Gervais 2018). The present section introduces the most important steps to realize a blockchain-based food supply chain.

The first step before choosing blockchain is to identify areas where problems in existing supply chains may occur and assess whether blockchain can actually help solving these problems (FAO and ITU 2019: 16f.; IP4: 10; Wang, Han, et al. 2019: 78). In many cases, a much simpler digital solution may be the answer (FAO and ITU 2019: 7). For a comprehensive evaluation, all participating stakeholders of a supply chain should be involved in the process of identifying problem areas. Then data security and privacy issues should be considered (Wang, Han, et al. 2019: 78). Since decision making and the determination of the consensus process are usually restricted to one lead organization (e.g., Migros, Walmart or Nestlé), this company decides who can participate in their network. Therefore, permissioned blockchains are particularly suitable for food supply chains (Cole et al. 2019: 471; OECD and KPMG 2019: 8; Pearson et al. 2019: 147). Depending whether public verifiability is required, a public permissioned blockchain can give reading access to end consumers. Otherwise, a consortium blockchain is suitable (see also section *4.4*). As the name indicates, it involves different businesses across a supply chain. It is important to note that a private consortium blockchain can handle more data than a public blockchain, which makes a private ledger more relevant if highly data-generating surveillance enabled by sensors is required (IP1: 81). Moreover, terms about the blockchain’s governance should be determined. This involves questions, such as the ways by which participants get access, leave the blockchain or how potential disputes among participants can be resolved (Wang, Han, et al. 2019: 79).

Finally, a blockchain platform should be chosen that fits the company’s requirements. Even though there is a plethora of blockchain platforms, most blockchains in supply chains are developed on either Ethereum, Hyperledger Fabric or R3 Corda. The latter two offer private blockchain solutions and provide limited tools for further developments (IP5: 64; IP6: 4; Wang, Han, et al. 2019: 64). Ethereum was launched as a public network but provides a great variety of tools (IP6: 4; Wang, Han, et al. 2019: 71). In the meantime, they also offer a consortium blockchain that is called Enterprise Ethereum (Coote et al. 2020: 47). Moreover, Ethereum and Hyperledger Fabric are open-source projects, while all three alternatives provide tools to develop smart contracts (FAO and ITU 2019: 4). In the beginning of blockchain development, Hyperledger Fabric was deployed by many companies because it was backed and promoted by IBM. However, Ethereum has the biggest community of developers, which makes it a very fast developing platform (IP6: 4; Suprunov 2018).

Once the type of blockchain and its platform is chosen, the onboarding process can begin. At the beginning of the onboarding process, the roles of all stakeholders along a supply chain are defined, and nodes are created. Nodes represent actors in the supply chain or an Internet of Things (IoT) device that send information to the blockchain. Hence, nodes can alter ownerships of assets and send updates, while all nodes act independently without impacting each other. Thereby, each node can provide information of production to the blockchain, such as on storage dates and conditions, time duration, food safety information and production methods (Galvez et al. 2018: 228; IP6: 54; Kim et al. 2018: 337f.).

To record a physical asset on a blockchain, a *digital twin* must be created. Such a digitizing process is commonly referred to as *tokenization* (IP5: 34; Kim et al. 2018: 336; OECD and KPMG 2019: 20). Thereby, a uniquely identifiable tag, such as an RFID tag, is attached to a physical asset that allows to digitally identify any individual product on the blockchain at any stage of production (IP5: 34). Hence, the ownership of a digital twin or token represents the ownership of its respective physical asset and can be transferred and moved along their digital supply chain. This allows all members of a supply chain to follow and interact with that digital twin (Kim et al. 2018: 336).

In general, the first node of the supply chain is represented by a producer (e.g., farmers or fishermen) who is the only stakeholder that can create a digital twin of a physical product. Depending on the chain member’s function and permission, each member can add or update data to the structure of the product. Then the asset moves along all nodes of the supply chain until it reaches its final consumers (Kim et al. 2018: 338). To enable an end-to-end traceability for end consumers and food companies, IoT devices, such as tags and sensors, must be linked with the blockchain at each stage along the supply chain. A tag makes a product uniquely identifiable and is placed on the product's package. Usually, an RFID tag is used, but near field communication (NFC) tags and QR codes are used as well to identify products or batches (IP5: 34; Kamilaris et al. 2019: 642). The RFID is an emerging provenance technology as it can easily be deployed within supply chains without changing whole business processes. It stores up to 32 kilobytes of data on each microchip that is successfully read in the first scan in 99.5 percent-100 percent of cases (Gopi et al. 2019: 299). By scanning a QR code or an NFC-enabled smart sticker on the food package, access to this information is granted by a consumer-facing app (IP8: 61, 81). The latter can be programmed to store cryptographically secure data, while QR codes store addresses of a digital asset on the blockchain. However, a 2D QR code can easily be copied at any stage of the supply chain and put on any other product, which would undermine the uniquely identifiable verification of a product (IP3: 32; Provenance 2016).

Furthermore, IoT sensors are required to obtain accurate information from the real world (Kamilaris et al. 2019: 648), while minimizing human input of data (OECD and KPMG 2019: 21). Sensory equipment comprise of devices that detect changes in location, temperature, humidity, motion, biological and chemical composition, but also cameras for facial recognition can be integrated (IP5: 24; Kshetri 2018: 86). The detected events are then recorded via smart contracts on the blockchain that are visible for all involved stakeholders (Wust and Gervais 2018: 49). Despite its recent emergence, smart contracts play a key role in SCM and are spreading quickly. They are particularly powerful if they can be connected to other digital sources and the physical world (Wust and Gervais 2018: 52).

To decide whether certain terms of a contract have been met, blockchains rely on external data sources that collect accurate information from the real world (IP3: 6; Kamilaris et al. 2019: 648). To link the physical world with the digital world *oracles* are required that are either hardware-based, software-based or consensus-based. IoT sensors are examples for hardware oracles, while software oracles retrieve information from web applications, such as from the New York Stock Exchange index or weather stations. A consensus-oracle takes decisions based on predefined nodes on a specific question (FAO and ITU 2019: 4). In this sense, oracles serve as a trusted third party by checking input data from the real world. This, however, makes oracles vulnerable to fraud since they decide whether a particular transaction is executed or not (IP3: 6; Kamilaris et al. 2019: 648).

5.2.4 The blockchain-enabled tuna supply chain

This section explains how blockchain technology is applied in practice for the tuna supply chain. *Figure 7* illustrates the simplified tuna supply chain that is blockchain-enabled and consists of five stages. The presented tuna supply chain does not represent one single tuna chain. Instead, the following information is based on several existing blockchain-enabled tuna supply chains. Next to the physical flow, there is the digital flow, representing various digital technologies such as QR codes, RFID, online certification, sensors, mobile phones etc. (Kamilaris et al. 2019: 642).

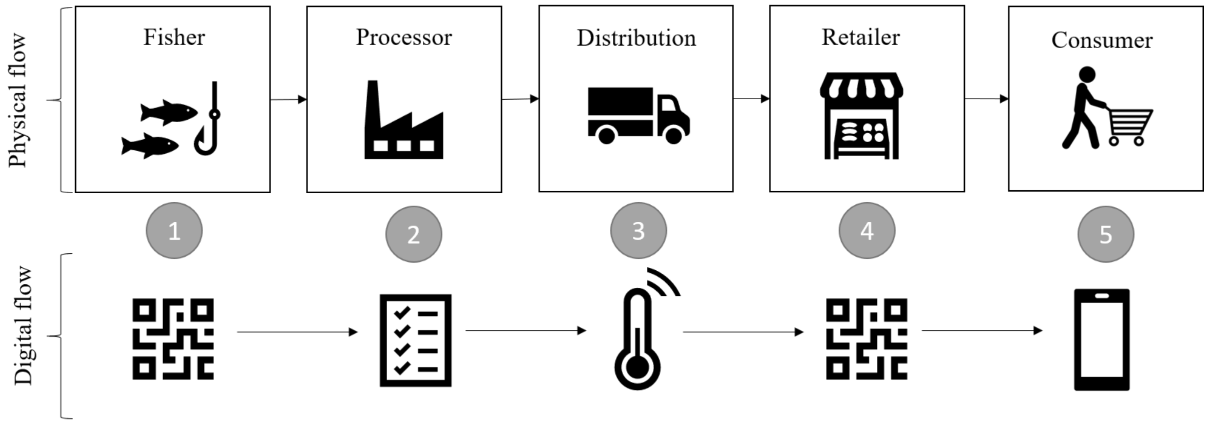

Figure 7 Simplified version of a tuna supply chain. Own illustration, based on Kamilaris et al. (2019: 642)

Before fishing vessels leave port to go fishing, responsible governmental authorities check data of the vessel and the crew, including their passports and contracts (IP8: 75). At the first stage, the fish is caught and tagged with a QR code (see *Figure 8)* or an RFID tag. RFID tags are applied with a gun that activates and timestamps the tags, providing accurate information about the date of catch (IP5: 40, 42). By applying this tag, a digital twin is created that represents the physical tuna on the blockchain (IP5: 34) and contains information such as the vessel's name, catching method, catching area, species and date of catch (IP6: 54; IP8: 82, 87, 89). In addition, every piece of fish is weighed (IP5: 46). Some data, such as the catching area, is monitored through equipped GPS trackers onboard the vessels (IP5: 24; IP6: 55-56), which are owned and authorized by the responsible national maritime authority (IP5: 42). Depending on the level of digitalization, cameras onboard the fishing vessels can be installed, ensuring that no illegal employment or modern days slavery is happening. This feature is not fully developed in the fishing industry yet (IP5: 24, 36).

Figure 8 A tagged tuna with a QR code (Visser and Hanich 2018)

In the next step, the tuna is brought to the processing facility (IP6: 50). Before processing, a third auditing party observes the measurement and the mass balancing of the fish. These documents are sent back to the government officials that oversee the fishing grounds (IP8: 75). They verify this information and check whether the volume complies with the pre-agreed catching quota (IP6: 50). Once the catch is verified and certified, the fish can be processed to loins or canned tuna, while a strict segregation of the different fish batches is ensured. A dilution with uncertified fish is prevented through yield verifications. Thereby, the incoming and the outgoing volumes are compared, while a certain amount of fish mass is lost at the processing stage due to the gutting of the fish, whereby eventually the yield rate is calculated (IP8: 49). In the end, only the volume of fish can be sold that was initially registered on the blockchain during the catching process. The system does not allow to sell more quantities than there actually exists (IP9: 9). To uniquely identify the fish, the lot numbers or a QR code of the specific fish are registered and printed on the product package. The identification information and further resulting information during the processing (e.g., certification, processor and processing date) is then immutably recorded to the blockchain (IP8: 75).

For the third stage of the tuna supply chain, the tuna is distributed to wholesalers or directly to retailers. During the transport, IoT devices monitor the storage conditions (e.g., temperature or humidity) and timestamps each transport steps (Kamilaris et al. 2019: 642). In case of any irregularities along the cold chain, smart contracts with integrated smart temperature sensors automatically trigger a notification to the digital twin on the blockchain (IP5: 34).

At the fourth stage, the tuna arrives at the retailer. The blockchain now contains detailed information about the quality, quantity, expirations dates and time spent on the shelf (Kamilaris et al. 2019: 642).

At the final stage, consumers can retrieve information from the blockchain by scanning a QR code on the package with their mobile phone. However, QR codes on the labels normally cannot uniquely identify the product. Instead, the QR codes direct consumers to a webpage, where consumers manually enter the imprinted lot number (IP8: 77). Unfortunately, the reading of this lot number requires mindfulness and patience because the numbers are sometimes difficult to read as zeros and “Os” are difficult to decipher (IP8: 95). *Figure 9* depicts a blockchain-based canned tuna with such a lot number on the lid. Retailers or other organizations then decide what information is available to consumers. Sensitive (e.g., prizing) and non-relevant information can be kept private (IP6: 54). In the case of the canned tuna of Gustav Gerig, which is available at the Swiss retailer Spar, consumers are given information about the species, catching area, catching method, catching period, processor, and production date.

Figure 9 Canned tuna with imprinted lot number and QR code for blockchain. Own picture, taken on 13 August 2020

5.3 Suitability and use cases

In theory, blockchain could be applied to any commodity. In practice, however, blockchain mostly makes sense in supply chains where mistrust and complexity prevail (IP4: 84). In general, mistrust occurs more often within high value chains because for those products, fraud is particularly economically viable. Hence, a trend for high value commodities can be observed for which blockchain is integrated (IP4: 60). As IP3 (16) emphasizes: “the more expensive and the more unique a commodity is, the more suitable a blockchain is.”

Furthermore, blockchain is particularly suitable for supply chains whose products’ sourcing may be ethically questionable (IP4: 60; IP9: 12). This brings up the question how blockchain can assist private certification ecolabels, which is discussed in section *6.2.3.* In addition, raw materials are more suitable than products that consist of multiple ingredients (IP9: 12). For example, proving the provenance of a frozen pizza is complicated since each single ingredient needs to be traced back to its origin (IP2: 26). A further applicable field for blockchain are commodities whose transportation and storage are prone to perdition, disease outbreaks or whose cold chain needs to be closely monitored (IP1: 41).

When considering all these criteria, I personally, regard tuna as an appropriate commodity to illustrate how blockchain-based traceability can assist its supply chain. Its supply chain is complex and disputed, while the cold chain for frozen tuna must not be interrupted. In addition, tuna has a high economic value and is traded internationally, while it normally comes as a raw material (FAO 2018b: 41). A counterexample of a disproportionate blockchain-enabled traceability system is provided by IP4 (86). He doubts the applicability for the farming of potatoes whose production is mostly local and cheap.

Table 4 lists all food commodities I came across during my research and interviews for which blockchain has been deployed. In addition, its purposes and involved parties are indicated.

Table 4 List of food commodities for which blockchain has been applied. Own illustration

Commodities	Involved companies	Goals	Sources
Crops	AgUnity	Empowerment of smallholders	Murthy et al. 2019
Patagonian Toothfish	OpenSC	Internal & public traceability	Whiting 2020
Palm Oil	Nestlé	Public traceability	IP5: 54
Olive oil	CHO, IBM	Public traceability & fighting counterfeiting	IBM 2020
Mangoes	Walmart, Kroger, Nestlé, IBM, Unilever	Internal traceability	Yiannas 2018: 52f., ITUNews 2018
Oranges	Carrefour	Public traceability	Carrefour 2020
Canned pumpkin	Nestlé, IBM	Internal traceability	ITUNews 2018
Wine	EZ lab, Ernest & Young	Public traceability & fighting counterfeiting	EZ Lab 2020
Pork	Walmart, IBM, Carrefour	Internal & public traceability	Kamath 2018: 47
Chicken	Carrefour	Public traceability	Carrefour 2020
Chocolate	Right Origins	Empowerment of smallholders	Right Origins n.d.
Salmon	Carrefour	Public traceability	Carrefour 2020
Tuna	Gustav Gerig, Atato, WWF, Provenance, ConsenSys, OpenSC	Internal & public traceability	White 2018, Whiting 2020 Provenance 2016
Organic fruits and vegetables	BioInspecta, Carrefour, Migros	Internal & public Traceability	Carrefour 2020, TE-FOOD 2019
Prawns	OpenSC	Public traceability	Whiting 2020
Dairy products	Molkerei Fuchs, Carrefour, Nestlé	Internal & public traceability	Stiller et al. 2019: 5, Carrefour 2020, IP5: 54
Eggs	Carrefour	Public traceability	Carrefour 2020
Potato purée	Nestlé, Carrefour	Public traceability	Nestlé 2019, Whiting 2020

5.4 Opportunities for food supply chains

Once the foundational infrastructure of the blockchain technology is deployed, it offers manifold possibilities how it can improve food supply chains (Iansiti and Lakhani 2017: 120; IP1: 39; IP3: 38; Yiannas 2018: 52). For this reason, this work aims to discuss only the most relevant applications that have been deployed. These involve mainly the traceability of products for end consumers, but also for food companies that aim to improve their supply chain processes (IP5: 28; Stiller et al. 2019: 9). In the following sections, potential benefits posed by blockchain within food supply chains are discussed. Thereby, the benefits are structured into two sections, each describing efficiency gains and social and environmental opportunities.

5.4.1 Efficiency gains

The enhanced efficiency of supply chains is one of the main drivers why so many food companies have invested in the blockchain technology. Thereby, efficiency gains are realized in various regards that are discussed in the following sections.

Real-time tracking

Due to the decentralized architecture of distributed ledgers, all transactions can be shared in near-real time with other stakeholders throughout the supply chain (OECD and KPMG 2019: 22). Even though a delay of several seconds or minutes may occur, the timestamped sequences of transactions is of great help to identify a product's origin within a supply chain. This enables enormous advantages compared to traditional databases for the management of supply chains where real-time tracking is unavailable yet (Azzi et al. 2019: 591; IP1: 45). For instance, it can help to fulfill dynamic storage management requirements and inventories. By providing location information of a product in real-time, it gives supply chain stakeholders the flexibility to manage logistics more accurately throughout supply chains (Galvez et al. 2018: 227; IP2: 2; IP3: 8; Jostock 2019: 9; Kehoe et al. 2017: 5). For example, Walmart could trace mangoes from farms in Mexico within 2.2 seconds, instead of seven days, using a traditional traceability system (Yiannas 2018: 51). Blockchain enables real-time tracking, which monitors conditions of storage and transportation, leading to an improved compliance with food safety regulations and savings at the same time (IP6: 68).

Integrating smart contracts

As stated in section *4.3*, smart contracts constitute key elements for an efficient SCM, thus leading to a higher level of automatization, cost reduction and security enhancements (Queiroz et al. 2019: 249). Even though smart contract features are still at an early stage of development, they are progressing fast (Wang, Han, et al. 2019: 74; Zheng, Xie, H.-N. Dai, et al. 2017a: 371). The potential applications for smart contracts seem limitless (Hughes et al. 2019: 276). This is in particular the case when IoT is integrated, which improves automated transactions (Kshetri 2018: 82).

Finding trading agreements between a producer and a supermarket as described in section *4.3* is only one example how smart contracts could be deployed in the food industry. Its applications are manifold, though. For instance, temperature sensors can monitor changes in temperature inside a refrigerated vehicle transporting perishable food. If the deviation in temperature exceeds a defined threshold a smart contract executes a notification to the blockchain. Thus, responsible stakeholders can take action in order to prevent distributing the affected products (Kehoe et al. 2017: 8). Such smart contracts have already been applied to monitor cold chains of seafood, assuring food safety (IP5: 34). However, Wüst and Gervais (2019: 49) illustrate in their work how easy it is to manipulate such a trusted temperature sensor in a refrigerating supply truck. To save costs, a supplier could simply put the sensor in a small fridge inside of the truck, while the rest of the products stays non-refrigerated, leaving room for loopholes.

There are other rudimental smart contracts in food supply chains that record changes of products' custody on the blockchain, which is triggered when it moves from one supplier to the next (IP5: 78). Furthermore, mass balancing checks can be conducted through smart contracts, diminishing the risk of subsequent illegal dilution (IP8: 49; Provenance 2016). Hence, smart contracts have a huge potential to improve efficiencies and curtail fraud along food supply chains (IP8: 45, 49).

Disintermediation

In the literature, blockchain has been commonly described to transform supply chains by replacing human intervention through automated transactions such as in the case of smart contracts (Casado-Vara et al. 2018: 393; Casino et al. 2019: 66; Kamilaris et al. 2019: 648; Queiroz et al. 2019: 241; Wang, Singgih, et al. 2019: 230). This process is referred to as disintermediation by which IoT technologies act as intermediaries between different parties (Kim et al. 2018: 338). According to the study of Queiroz et al. (2019: 249), disintermediation is expected to increase in the coming years due to the adoption of smart contracts.

Based on the smart contract approach, assets can be automatically transferred without the need of a trusted third party that supports the transaction verification and validation (Attaran and Gunasekaran 2019: 22; Queiroz et al. 2019: 241). Hence, blockchain has the potential to make some intermediaries redundant, such as wholesalers or quality auditors, and speed up transactions, while reducing transaction costs. Thereby, trust is no more needed between the parties, as automated transactions are executed (IP4: 92; Queiroz et al. 2019: 243).

While some interviewees agree to the phenomenon of disintermediation induced by the introduction of blockchain (IP5: 80; IP6: 78), others disagree. Some claim that as long as intermediaries provide an added value to supply chains, such as conducting measurements or quality management, they will not be phased out (IP2: 49; IP3: 14). In addition, due to manageability, IP9 (26) is convinced that large enterprises prefer to work with few traders, instead of working with hundreds of smallholders.

Economic sustainability

Blockchain can also contribute to economic sustainability as IP5 (46) explains how big data can improve efficiency within the fishing industry. Thereby, each piece of fish is weighed, and its information is recorded via an RFID tag to the blockchain. If fishers start catching too small and immature fish, they discard the fish and go fishing somewhere else. This data can be compared to the GPS data, which gives fishing companies crucial information where they found immature fish with low weights. Consequently, they can figure out at which fishing grounds they can find mature fish for the next season. Thereby, fishermen can fish more efficiently and catch fish that has the optimal size. Since fisheries have the permission to catch only a certain quota of a specific fish, they want to reach this quota with as few catches as possible. Thus, they can finish their fishing trip earlier, which results in using less fuel as well (IP5: 48).

Enhanced trust

Trust is important for successful business cooperation (Stiller et al. 2019: 15). However, traditional trust is normally built through long-term relationships and does not cope with the spontaneous demands required in digital business. As Gaehtgens and Allan (2017) put it:

> "It is often said that trust takes years to build, seconds to break and forever to repair. Digital trust, on the other hand, takes instants to build, an instant to break and is continuously adaptive." (Gaehtgens and Allan 2017: 3)

Digital trust can particularly help in environments where actors do not know or trust each other. In the case of retailers that have established long-term busines relationships, a high level of trust already exists and a blockchain with a relatively low number of ledger copies and simple consensus rules would be appropriate. On the other hand, in supply chains with a limited prior relationships or fewer audit controls, a higher number of nodes with a more robust consensus mechanism is desirable (Pearson et al. 2019: 148). In the latter case, a public blockchain is advisable as it offers a higher level of trust (IP1: 51).

According to several scholars and entrepreneurs, blockchain is an effective solution whenever there is an issue of trust among network participants (Pearson et al. 2019: 148; Schlegel et al. 2018: 3478; Yiannas 2018: 54). Wang, Han, et al. (2019: 76) state that trusting supply chain partners may become irrelevant when blockchain is applied because trust has been programmed. Instead, stakeholders only need to trust the blockchain technology itself (Schlegel et al. 2018: 3478). Due to its decentralized and tamper-proof storage of data, blockchain technology enables digital trust, which is one of its main strengths (Galvez et al. 2018: 226). The consensus mechanism and resulting transparency underpins trust since participants can verify the quality of the data of each other and everyone has a copy of the transaction ledger, creating a single source of truth. Hence, malicious stakeholders could easily be exposed and sanctioned (Pearson et al. 2019: 146f.).

With blockchain, trust can be established at every stage of the supply chain. It is not only important for trading partners, but also for end consumers (IP9: 14). According to IP8 (101, 103), consumers actually barely use traceability systems, but they want to have the opportunity to gain access to this information, which gives them the feeling that data is more reliable. Hence, making supply chains visible to consumers, strengthens customer confidence towards a product, a brand or a company (Gopi et al. 2019: 302).

Blockchain as a marketing instrument

Enabling end user experiences with public verifiability can be an effective strategy for retailers to demonstrate the superior quality of their products. Thereby, a retailer’s image and the branding of products can be strengthened, which in turn boosts loyalty among existing consumers, while attracting new ones. Thus, a retailer can stand out from its competitors, giving them an economic incentive to participate in a more sustainable production (Galvez et al. 2018:

226). For instance, Carrefour experienced higher sales for blockchain-enabled chicken than for non-blockchain-enabled chicken (Thomasson 2019).

Hence, there is an accordant agreement among the interviewees that blockchain is in many cases applied for marketing reasons (IP1: 69; IP2: 6; IP4: 96; IP5: 76; IP6: 68; IP8: 45). As IP5 (74-76) states, retailers are happy to announce the introduction of a pilot project with integrated blockchain since it induces press releases, which they were seeking for in many cases. It seems to him as if press releases were announced weekly, in which retailers claim to trace a product with a blockchain-based platform. According to IP4 (96) and IP8 (103, 140), by inducing such press releases, retailers want to show that they are forerunners and innovative, which gives them the first mover advantage. Even IP2 (6), who is a retailer representative, admits that in their case, the newspaper inflated the expectations of their blockchain deployment. Furthermore, the blockchain-based food traceability company, TE-FOOD, promotes using blockchain explicitly as a marketing tool since consumers appreciate transparent information and its introduction leads to headlines in newspapers (TE-FOOD n.d.).

Tamper-proof concept

There is according agreement that any system can potentially be tampered with (IP1: 83; IP3: 6; IP5: 38). However, IP1 (111-113) and IP5 (38) are convinced that systems can be developed intelligently, making the effort economically unviable to cheat.

One main advantage of the blockchain technology is that once data has been recorded, no transaction can be manipulated, making the concept tamper-proof against hacks and corruption (Galvez et al. 2018: 226). Protecting data during the whole supply chain is crucial for the product’s quality (Azzi et al. 2019: 589). Through blockchain, a better monitoring of the moved volume throughout supply chains can be enabled, which prevents subsequent illegal dilution with non-certified products (IP9: 8). For instance, a wine producer cannot produce more wine than he received from the harvest of a certified grape grower (OECD and KPMG 2019: 16).

Moreover, due to the blockchain distributed characteristics, no single entity controls the network and hence no single point of failure in the system is created. This prevents the manipulation of data by stakeholders since all transactions must be approved by all other participants by reaching consensus about the newly added blocks to the blockchain (FAO 2018b: 179).

However, at this point, it is important to clarify that blockchain is not a solution that ensures the quality of data entering to the blockchain. As IP7 (14) puts it: “garbage in, garbage out.” If incorrect data enters the blockchain the outcome of the data ledger is useless. So far, it assures only that the recorded data cannot be altered unnoticeably during the supply chain (IP6: 48). Hence, the data entering the blockchain can still be tampered either by human error or by tampered sensors. Yet, once data is on the blockchain, it stays tamper-proof and cannot be altered. According to IP5 (24), not even the blockchain platform provider is able to modify data once it is recorded. Thereby, subsequent malicious dilutions can be prevented (IP9: 8).

Finally, blockchain will not be able to fully prevent malicious activities. However, in case of violation, the origin of fraud can be identified and sanctioned if necessary (IP3: 20). Thus, blockchain can be regarded as an effective tool to reduce fraud and malicious activities along the supply chain (Azzi et al. 2019: 591).

5.4.2 Social and environmental opportunities

In this section, social and environmental opportunities enabled through blockchain are presented. Frist, arguments leading to consumer empowerment are provided. After this, enhanced food safety and finally sustainability benefits are discussed.

Consumer empowerment

As stated above, consumers increasingly demand to know how, when and where products were sourced and processed (IP3: 8; IP6: 38). IP5 (12) is convinced that blockchain-based supply chain traceability systems enable such demanded transparency to supply chains, which allows consumers to make informative decisions that are aligned with their own values. Some insist on regional products, while other prefer organic products (IP3: 8; IP9: 15). However, this demand depends strongly on the geography of the markets. While people in Western Europe and the USA are becoming more aware about a product’s sustainability, its demand remains rather low in the main emerging consumer markets such as in India, China and Brazil (Dauvergne and Clapp 2016: 85; Gereffi and Lee 2012: 28; IP4: 64).

Moreover, by using biosensors that are linked to the blockchain, undeclared allergens can be detected, leading to enhanced food safety for consumers with allergies (Azzi et al. 2019: 588). Further claims, such as products being local, non-GMO, glyphosate-and antibiotic-free or kosher could be assured by blockchain as well since every stage of the supply chain is retraceable (Galvez et al. 2018: 223; Johannes 2020; Radocchia 2019).

Considering that many food supply chains are strongly buyer-driven (Adolf, Bush, and Vellema 2016: 81), and consumers are the market driving force, consumers exert pressure on retailers (Kamilaris et al. 2019: 647). Hence, retailers are likely to improve their transparency of supply chains in order to meet the demands by empowered consumers (Schlegel et al. 2018: 3478). Thereby, pull factors are created that may lead to more transparent, sustainable, safe and fair food productions (Kamilaris et al. 2019: 647). This in turn can lead to a positive rebound effect as the consumers' confidence towards a retailer or brand is enhanced, which consequently leads to higher sales (Wang, Han, et al. 2019: 72). Finally, due to improved trust by enabling full transparency, conscientious consumers are willing to pay higher prices for premium products since an added value is offered (Provenance 2016).

However, a retail representative (IP2: 40) perceives blockchain-enabled public verifiability as gadgetry and states: "if provenance and standards are important to consumers they should stick to ecolabels." IP8 (47) believes that such responsibility should not be at the consumer level as they are not fully aware about the issues in global food production. In addition, she states that only a minority of consumers take the time to use traceability systems and inform themselves about a product's history (IP8: 103). Instead, she suggests that consumers should trust the industry players who are accountable for their products (IP8: 47).

Food safety

Food safety describes the processing, managing and storage of food in hygienic ways with the aim to prevent outbreaks of foodborne diseases (Kamilaris et al. 2019: 643). As described in section *5.1*, traditional traceability systems lack in speed and efficiency due to largely relying on obsolete paper records. Hence, traditional traceability systems take several days to track products back to its origin, whereas blockchain can trace products within a few seconds. Such an improvement is crucial when it comes to immediately needed product recalls in case of occurring illnesses, thus it can significantly contribute to food safety. Hence, food companies can react faster and save time, hindering the spreading of foodborne diseases (IP6: 68; IP7: 22; Kshetri 2018: 84; Wang, Han, et al. 2019: 72). Moreover, as described in the previous section, smart contracts can monitor storage conditions, assuring that cold chains have not been interrupted. In this sense, effective traceability systems are critical tools to ensure food safety (Pearson et al. 2019: 146).

Promote sustainable practices

Blockchain can promote sustainability in all three dimensions: social, environmental, and economic. The economic opportunity is described in the previous section, implying that fisheries can fish more efficiently. Transparency is also claimed by a great variety of stakeholders as it ensures socially and environmentally sustainable practices throughout food supply chains. With blockchain, this demand can finally be met with relatively low efforts. Making unethical and illegal practices visible to the public, puts pressure on producers to improve their existing production methods. Hence, giving consumers the power to make informative decisions is one way to improve the sustainability throughout food supply chains (IP5: 28). Two interview partners (IP5: 24-26; IP6: 106) are convinced that blockchain can also improve sustainability by raising awareness about environmental and social responsibility issues in the food production. In this sense, providing ethical information about products' sourcing methods can gain momentum and galvanize a change in consumers' behavior towards more sustainable consumption (Provenance 2016). Furthermore, companies are encouraged to keep up their environmental and social practices since their efforts are often not fully recognized due to traditional opaque supply chains (Cook 2018: 6). As IP1 (31) states, with blockchain-enabled transparency, however, small-sized suppliers can provide proof of their actions, which verifies the quality of their products and production methods.

As shown by the use case of the tuna supply chain in section *5.2.4*, sustainable fishing practices can be ensured, by providing proof that the fish was caught in legal waters. Therefore, some authors claim that blockchain can end IUU fishing practices (Kshetri 2018: 86; Word Economic Forum 2018: 13f.). As Bubba Cook (2018: 12), a tuna program manager at WWF, puts it: "it [blockchain] has the potential to rewrite the rules for the sustainable and ethical production and consumption of any commodity, including seafood products, on a global scale."

Finally, social sustainability can be improved with blockchain-enabled traceability systems. As mentioned above, illegal workers and working conditions on vessels can be monitored with facial recognition. A further argument of how blockchain can mitigate social inequalities and empower smallholders is shown in section *6.2.2*.

6 Challenges and future of blockchain

First, this chapter presents unresolved challenges around implementing blockchain in food supply chains. Second, transformations enabled through blockchains are displayed. Thereby, disintermediation, the suitability for small-size entrepreneurs and the potential impact on ecolabels are discussed. In a next step, a synthesis compares the two main use cases, while an outlook is provided at the end of this chapter.

6.1 Challenges and obstacles

While focusing on tuna, this work also discusses other commodities, for which blockchain technology has been implemented. At this point, it is important to mention that each commodity is differently sourced and produced and thus has a different supply chain. Therefore, some of the following discussed challenges and its respective solutions may be appropriate for some commodities, while they might not be applicable for others.

6.1.1 Lack of understanding and adoptions of blockchain technology

The technical complexity of blockchain technology makes it difficult to understand its underlying concept. Thus, many people are not aware about its application fields. This opinion is shared by several interviewees, which poses a major barrier for the widespread adoption of blockchain (IP1: 63; IP5: 88; IP6: 96; IP7: 10). In addition, IP5 (88) believes that some negative perceptions around blockchain may be created as people associate this technology with speculative cryptocurrencies, while they are not aware about the other use cases. This in turn may lead to mistrust towards blockchain technology (IP5: 84).

Fully understanding the technology and its use cases is not only difficult for end users, but for companies and its stakeholders as well. According to IP6 (18), it takes a lot of persuading to convince companies how blockchain can assist their existing businesses. IP7 (10) thinks that other companies do not see any added value for their business cases, which might be attributed to their lack of knowledge around blockchain. Similar aversions have been observed by IP5 (24) among fishermen and farmers who do not see its value. However, their inclusion is required to provide a complete history of a product.

IP6 (44) compares this aversion of adapting to new technologies with the introduction of the internet in the early 1990s, when companies were wondering what they need a website for, if people could simply call them to know what kind of company they are. IP1 (63) points out that blockchain is still an emerging technology and people have gradually heard about it. He sees analogies of its slow adoption with the introduction of credit cards. At the beginning, hardly anyone used credit cards or automated banking, whereupon it took several years until its mainstream adoption. This statement is consistent with the one of Iansiti and Lakhani (2017: 120) who describe similarities between blockchain and the internet as well. They believe that the adoption to blockchain technology will be a gradual and steady process and it will take decades until is full adoption.

Since blockchain is still in its infancy, limited numbers of adoption exist so far, excluding the financial industry. This poses a further obstacle because the technology is not as advanced and mature as other proven existing data storage technologies (IP1: 115). Although many companies are gaining experiences with blockchain through realizing pilot projects, most of them fail to reach proof of concept, which hinders them to pursue further deployments with this technology (IP5: 76).

As IP1 (131) states, it is generally difficult to shift industrial infrastructure that has been used for more than 30 years to something new, like blockchain technology. Due to this reason, he argues that most companies prefer to use existing technologies that they understand and have been proven (ibid: 131). According to IP5 (86), adoption to technology is generally slow, while particularly large-sized companies are hesitant. These corporates have a lot to lose in case of failure of their network system. This is especially the case when blockchain is integrated in existing ERP-systems, which are core tools for every company. Hence, there is a lot of waiting and analyzing how other companies are getting along with blockchain before the technology is widely integrated in the SCM (IP5: 86). In this sense, IP7 (20) emphasizes the importance that companies increasingly initiate small-sized pilot projects and publish their experiences through which other companies and industries are able to gain insights on how blockchain can and cannot help. IP7 (20) uses the metaphor “you can’t boil the ocean” to illustrate that the adoption of the blockchain technology should be realized in small steps.

To teach companies and other stakeholders along supply chains how blockchain can assist their businesses, education and trainings must be conducted. Educating companies can be realized in forms of forums, such as at the World Economic Forum, the Global Forum, or other conferences where representatives of various industries come together and exchange information around blockchain (IP7: 12).

6.1.2 Lack of standards and regulatory frameworks

Since the number of blockchain-based applications is growing, many heterogeneous solutions are created in digital information silos (Casino et al. 2019: 71). However, due to various standards and communication systems, deficient interoperability with existing systems and the ones with other actors along supply chains is created (IP2: 23-24; IP8: 65). A regulatory framework is particularly necessary in use cases where intermediaries are absent and automated transactions are executed with the help of sensory devices because the sensors' accuracy and functions needs to be defined (IP1: 133-135; Wang, Han, et al. 2019: 77).

Therefore, there is accordant agreement that a data standardization is strongly needed for a better blockchain-based cooperation (IP1: 117; IP2: 33; IP3: 8; IP7: 18; IP8: 63). As IP8 (61) states, developing a standardized language that defines what data is needed and what it stands for is key for a successful collaboration in supply chains. However, she explains that there is still a lot of confusion handling data from different stakeholders in practice. For instance, in the fishing industry, there are various ways to determine the start date of a fishing trip. Some determine this date when fishing vessels leave port, while others define the start of fishing when fishermen have reached fishing grounds and start fishing. Finding a consent about the fishing date might seem less relevant, while determining the volume of catch may lead to greater problems since different measurement approaches exist. Consequently, she argues that such discrepancies may lead to confusion, which hampers a successful collaboration among the involved parties.

Moreover, in the case of public verifiability, IP3 (8) states that it is difficult for end consumers to keep track of all the available traceability systems. Having installed a plethora of different traceability apps on the mobile phone brings up the question, whether these services can still be regarded as customer-friendly. For this reason, he suggests that retailers and other food companies could agree upon one application interface that meets all their requirements and therefore increase the ease of use.

However, according to IP1 (137), the retailing industry is still far away from finding such agreement on standards, whereas these difficulties have not been overcome in the further advanced financial sector either. He expects some kind of regulation for blockchain applications in the next ten years, though. He further argues that other use cases next to supply chains rely on regulations as well, increasing the necessity for general regulations. It seems to IP3 (10) that no one feels responsible for such a standardization and no one wants to face this challenge. However, many scholars promote that blockchain solutions should utilize and be developed on existing standards, such as the one by the International Organization for Standardization (ISO) and GS1 (Chang et al. 2020: 2092f.; FAO and ITU 2019: 13; Kim et al. 2018: 337; OECD and KPMG 2019: 11; Yiannas 2018: 54). ISO created the technical committee called ISO/TC 307 that consists of more than 50 participating countries to meet the growing need for standardization in blockchain. According to the committee's Chair, Craig Dunn:

> "we [ISO] can achieve that by providing internationally agreed ways of working to improve security, privacy, scalability and interoperability and so encourage the technology's widespread adoption through greater innovation, enhanced governance and sustainable development" (Oclarino 2020)

Moreover, there is GS1, a neutral nonprofit organization, which develops global standards across industries. They are best known for the introduction of the barcode that uniquely identifies products (GS1 2019: 8). Using GS1 standards for unique identification, such as batch/lot, Global Trade Item Number and Global Location, can enable interoperability for traceability in an inter-organizational environment. Here, the standardized definition of the ledger components is key (ibid: 4).

6.1.3 Interface between the physical and the digital world

On paper, the blockchain technology seems indeed as a revolutionizing technology that has the potential to transform the SCM. However, when it comes to interface the digital with the physical world, many challenges occur (IP5: 24; Wust and Gervais 2018: 49).

A widely discussed challenge is the verification of the raw data entering the blockchain, which is elsewhere referred to as the *first-mile problem* or *gate problem*, indicating the process where a digital twin of a physical asset is created (IP3: 6; IP4: 10; OECD and KPMG 2019: 19f.). The key question here is, how the quality of the data is verified since actors could register incorrect data by mistake or by intentional fraud (IP1: 107; OECD and KPMG 2019: 20f.). IP6 (48) points out that blockchain does not solve this problem yet as the quality of the data relies on the source of data. For this reason, IP8 (43) sees strong limitations for the usage of blockchain if the entire validation relies on the first entry of data. Thus, she questions the whole logic behind blockchain as it is not clear how input data is verified in a decentralized distributed ledger by the other participants.

Indeed, the verification mechanisms are usually different in permissioned blockchains than in public ones. As stated in section *4.5*, public ones normally use the PoW or PoS algorithms, while permissioned blockchains make use of BFT protocols. The difference is that permissioned networks require a higher level of trust among all involved participants as verifying nodes are selected based on predefined rules. Hence, stakeholders need to trust the data of the other participants (IP1: 103). Blockchain does not diminish the threat of unintentional human error nor does it address intentional frauds. However, trust can be increased by minimizing human interactions. Instead, trusted IoT devices such as sensors should be deployed according to IP1 (45).

To illustrate a real case of such verification, IP5 (40-42) demonstrates how members of a blockchain-enabled fish supply chain want to verify whether fishing vessels had been fishing in legal waters. Since the GPS data of the vessels are mandatorily available to the public, this data can be compared with the timestamped GPS data provided through the RFID tag of the caught fish. In addition, he explains that machine learning algorithms are fed with information of the vessel's speed, depth of the ocean and weather conditions, thereby restricting the fishing area. Since fishing vessels can only fuel their lines at a certain range of speed and at specific wind directions, this data is compared with the cardinal direction of the fishing vessel. Thus, it can be detected whether vessels navigating through protected areas had been fishing. Moreover, he clarifies that certain fish species, such as toothfish, live in 2000 to 3000 meters depth below the sea surface. This makes fishing toothfish suspicious to illicit activities if it was caught in shallow waters. According to IP5 (40-42), when analyzing and comparing all these fishing criteria with machine learning algorithms, a certainty level of more than 90 percent can be reached, assuring that no fish was caught in illegal waters.

Yet, IP3 (6) states that even automated processes and algorithms bear pitfalls as they can be manipulated by programming oracles in a certain way that they retrieve information from intentionally false sources with the aim to trigger a transaction that is in favor for one party but severely disadvantages other parties. For the aforementioned case of determining whether vessels had been fishing in illegal waters, oracles could be programmed in a way that weather data is retrieved from dubious weather stations. Alternatively, persons who are in charge of these stations could be bribed or GPS trackers could be simply manipulated, creating a loophole for malicious activities.

6.1.4 Tradeoff between transparency and privacy

On the one hand, providing full transparency with a public blockchain for all stakeholders of a supply chain may improve collaboration. On the other hand, sensitive information may be revealed, creating an inherent tension between transparency and privacy (Wust and Gervais 2018: 46). This hinders many companies to disclose their production processes, which prevents them to participate in public blockchains (IP7: 16) as many actors are competitors in the food industry and pricing is usually not publicly communicated (IP2: 38). Hence, IP9 (18) points out that many stakeholders resist to provide full transparency because some actors profit from too high margins. According to her, some positions in the supply chain may not be fully justified as they function solely as traders and do not provide any added value.

For this problem, IP1 (103) suggests implementing a permissioned blockchain. Thus, companies can define what information should be visible to their business partners, while privacy over sensitive information can be assured. There are also approaches to restrict access to certain information in public blockchains based on the assigned role or user, though (Cook 2018: 12).

At this point, it is important to mention that if blockchain is abused it can facilitate malicious activities, such as IUU fishing, resulting in overexploitation of resources (FAO 2018b: 181). Such a dilemma between full transparency and the integrity of data is exemplified by IP8 (121). She argues that fully transparent public blockchains could disclose sensitive data such as the identity of the auditing observers on fishing vessels. Such a disclosure would directly play into the hands of malicious actors as it helps them to systematically bribe those observers, which would be totally counterproductive as it fosters overexploitation.

6.1.5 Financial constraints

Another obstacle constitutes the cost for the implementation of a blockchain-based traceability system (IP4: 60). The costs to implement a blockchain vary greatly as it depends on the number of actors in a supply chain, what kind of product needs to be traced, what kind of sensors are deployed, how much data needs to be stored, what kind of additional features (e.g., smart contracts) are desired and what kind of traceability system already exists (IP1: 53; IP5: 58; IP9: 10). IP5 (58) explains that there are usually three main drivers that account for most of the costs. These are the consulting fees, the chosen hardware (e.g., sensors and its receivers) and the ongoing operating costs. The latter comprise transaction fees, platform fees and power costs. As IP1 (53) clarifies, the transaction fees depend on the amount of data that is to be stored and whether automated checking is conducted by smart contracts. If data is in the scale of kilobytes the transaction will cost about US$ 1, which does not seem much. However, some systems are designed to conduct such a transaction every hour or even every five minutes, leading to rapidly increasing costs.

Yet, IP9 (10) believes that blockchain-enabled traceability systems are inexpensive compared to other traceability software, while the costs will decrease over time. Furthermore, she states that the initial implementation of a blockchain for a simple supply chain amounts to US$ 10,000, while monthly platform fees of US$ 30 are charged. IP3 (32) estimates the costs to realize a pilot project vary between US$ 40,000 and 50,000. Moreover, he points out that once a working traceability system is created, it can be easily adapted to any other commodity, making future implementations more affordable. IP6 (68) is convinced as well that blockchains are inexpensive solutions, while retailers gain a marketing instrument by providing transparent supply chains for their customers, which in turn results in increased sales.

Furthermore, there remains a challenge around the costs for the installation of tags and sensors. For example, it is not economically viable to attach an NFC tag to each egg in order to trace its supply chain history, since the price for an egg is below the tag’s price of US$ 1 (IP3: 6). Similarly, it may not be profitable for inexpensive commodities to install temperature loggers that monitor the cold chain. IP5 (34) clarifies the question how the price for the installation of such a temperature sensor is justified when the prices for certain commodities are rather low. For this, he brings up the example of a box of prawns that retails for US$ 80, while the cheapest temperature loggers with an adequate battery life go for US$ 10 the piece. In this case, it is not economically viable to trace the temperature of each box. If the temperature logger is attached to a pallet that contains 250 boxes of prawns the economics change, though. Hence, there is a tradeoff between accuracy and economics since the temperature data from a pallet is not as accurate as having data from each single box.

However, IP5 (58) believes that the costs may be too high for smallholders and small-sized entrepreneurs with limited budget to integrate blockchain in their processes (IP5: 58). Yet, the inclusion of producers is a prerequisite for making the entire supply chain history visible (IP7: 20). This argument is discussed in more detail in section *6.2.2*.

6.1.6 Technical challenges

Several technical constraints regarding the implementation and operation around blockchain were mentioned during the interviews. The most important ones are concerning scalability issues and the energy consumption resulting through the consensus mechanisms. These two challenges are now described in the following sections.

Tradeoff between scalability and security

First, scalability remains a key technical challenge (IP1: 93; IP6: 16) in terms of throughput and latency (Tian 2018: 92). The latter describes the time delay for each transaction needed to be added to the ledger, which occurs for Ethereum approximately every 17 seconds and is still far away from the milliseconds that other conventional databases offer (Wang, Han, et al. 2019: 74). The amount of data being transferred depends on the number of system users (nodes), since each node has its own copy of a ledger. Given the large number of actors involved in global food supply chains, a huge amount of data is generated. Moreover, some food products consist of multiple ingredients, while various secondary supply chain providers may be involved as well (e.g., refrigeration companies, audit and assurance companies and labelling companies), which accumulates large volumes of metadata (Pearson et al. 2019: 148). In addition, integrating IoT devices keep on straining the storage of data, leading to a decreased blockchain performance since only a limited number of transactions per second can be handled. Hence, scalability is particularly a challenge for complex supply chains that use a public blockchain, while private blockchains can handle larger quantities of transactions (Azzi et al. 2019: 587; IP1: 93). There is ongoing research addressing scalability issues by either optimizing the storage of blockchain or redesigning blockchain. The latter divides the ledger into two parts: a key block for leader election and a microblock to store transactions (Zheng, Xie, H. Dai, et al. 2017b: 562).

Second, technical vulnerability seems to be a far-reaching issue. As mentioned above, any IoT device can be manipulated but the whole system could be hacked as well, leading to security concerns (IP1: 93). However, tampering with public blockchains by one node is nearly impossible, unless one can control 51 percent of the nodes in the system. Since private blockchains are centrally managed, a single point of failure is created. This makes the whole system vulnerable to hackings and corruption, which contradicts the underlying principles of blockchain technology. Consortium blockchains are less affected by this threat as several nodes are involved in the decision-making processes. Hence, the more nodes in the system, the more secure the network will be, implying that public blockchains are the most secure ledgers (Tian 2018: 16, 85). IP4 (102-104) points to the far-reaching risk in case such a hack or intentional manipulation of a blockchain is detected and goes public. Consequently, the blockchain technology's reputation will be severely damaged, resulting in a loss of trust in the technology. On the other hand, such malicious users can be identified and sanctioned, and restrictions can be spoken out (IP3: 20). This bears the risk, however, that innocent parties might be incorrectly sanctioned (Pearson et al. 2019: 147).

Furthermore, due to the immutability offered by blockchain, the concept is tamper-proof once data has been recorded. However, this comes at the disadvantage that wrong input data by mistake cannot be reversed (IP3: 6). Private blockchains can partially handle such a deletion of data, however, only at the cost of compromising the underlying trust model (Stiller et al. 2019: 71).

High energy consumption for reaching consensus

Many scholars have criticized the high energy consumption due to the computational power needed for the consensus mechanism that verifies the transactions (Kshetri 2017: 1720; Queiroz et al. 2019: 251). The energy consumption caused for Bitcoin is estimated at 70 terawatt hours for the whole year of 2018. This is more electricity than Switzerland used in the same year (Smith 2018).

Indeed, the high energy consumption of public blockchains poses a high hurdle to overcome as many food traceability systems are based on Ethereum that usually uses the energy-intensive PoW mechanism (IP1: 95; IP5: 64). This, in particular, is inconsistent when companies have sustainability claims but are using energy wasting technologies (IP5: 64). However, a lot of research has been done in this field to shift to less energy-consuming mechanisms, such as PoS, PoA or PBFT. Yet, these low energy mechanisms have been mostly deployed in private blockchains (IP1: 93, 95).

A reliable private blockchain operates the same way as a public one does (IP1: 103). However, a private blockchain uses fewer computational power as there is no need to conduct a sophisticated verification of each node since its participants are known. Thus, a closed system is less prone to attacks (Casino et al. 2019: 57; Tayeb and Lago 2018: 37). As a matter of fact, industries are not waiting for better mechanisms and work with the currently available technologies. But they know that they eventually will change to more suitable mechanisms (IP5: 68). As IP5 (64), a blockchain solution provider, puts it:

> "our guiding theory around blockchain is that we believe that blockchain is today where the internet was in 1996. The same way, you don't build websites with flash anymore, in ten years, no one will be building stuff with Ethereum, or with the current version of Ethereum at least."

6.2 How blockchain transforms food supply chains

Many scholars support the idea that the technology will be revolutionary and transform existing businesses (Kshetri 2018: 81; Queiroz et al. 2019: 249; Tian 2018: 22; Wang, Han, et al. 2019: 79). Yet, blockchain's impact on food supply chains is still largely unknown. This section presents the potential transformations in the food industry facilitated by blockchain. First, its impact on redundant intermediates is discussed. Second, the applicability and opportunities for small-sized companies and smallholders in developing countries are evaluated. Finally, arguments are presented what blockchain means for food certifying ecolabels.

6.2.1 Disintermediation

As mentioned in section *4.6*, many scholars perceive blockchain as a potentially disruptive technology because disintermediation is expected due to higher levels of automatization (Kamilaris et al. 2019: 648). Such an incidental disintermediation in food supply chains caused through blockchain is not supported by all interview partners, though.

On the one hand, two blockchain providers predict disintermediation. IP5 (80) argues that the marketplace represents the trusted third party that mediates an exchange of assets. If the rules of such transactions can be codified within smart contracts (as described in section *4.3*), the marketplace is no longer needed. He compares this process with eBay and Airbnb that function as intermediaries and enable cheaper transactions, whereby jobs had been become redundant. Even though new jobs will be created in the blockchain-related domain, employment within traditional food supply chains will decline, leading to a fraction of its initial costs for managing food supply chains. The other blockchain provider (IP6: 77-80) agrees with this assumption insofar as redundant middlemen will be left out, but these positions will be reskilled for other tasks along supply chains such as providing quality reports, control and auditing reports or within application processes. This opinion is shared by IP7 (28) who expects a shift from routine-intensive employment towards more strategic and cognitive job tasks such as for recall processes.

On the other hand, the majority of the interview partners do not envision that blockchain will have such a strong impact on employments along food supply chains (IP1: 127; IP2: 44; IP4: 76; IP7: 36; IP9: 26). Instead, they think that disintermediation is anyway an ongoing process that primarily depends on the business strategy of the concerned stakeholders. They are convinced that as long as intermediaries offer an added value, such as measuring, auditing and consolidating goods, they will be part of the supply chain (IP2: 44; IP7: 36; IP9: 26). The third blockchain solution provider (IP9: 26) shares this opinion and states that intermediaries, such as wholesalers, will continue to persist, whereas some may disappear. Yet, she clarifies that there will be only a few actors concerned by this threat as most of them have vanished by now.

According to the International Labour Organization (ILO) (2017), the demand for technological advancements in automation systems has risen considerably in recent years, significantly impacting the job market. The robotization of the economy has the potential to bring large productivity gains and create new jobs. Yet, its impact on societies will depend on how economic growth will be distributed. According to the ILO (2017), considerable investments in trainings and skills upgrading is required to facilitate a smooth transition from existing to new jobs. Moreover, the robot density in manufacturing is unevenly distributed over the globe. In developed countries, 14 industrial robots per 1,000 people were employed, while developing countries had an according value of two for the year 2015. Therefore, according to Díaz and Grau Ruiz (2020: 342f.), the number of lost and won jobs will strongly vary for each country. Furthermore, they state that the countries that are able to reskill their workforces, will experience a shorter technological transition period, helping them to achieve a competitive advantage using automated systems. Since the reskilling of human workforce poses a challenging endeavor, it is also on the agenda of the European Parliament (ibid: 349).

6.2.2 Suitable for small-sized companies and smallholders?

In academic literature, it has been discussed whether blockchain can be regarded as a chance for small-sized entrepreneurs and companies or whether the technology is rather attracting big companies. Some say it can improve market access for small actors (Kamilaris et al. 2019: 644; FAO 2018b: 179), while others say that the initial investment costs pose a too high barrier to participate (Gopi et al. 2019: 299). An according divergence of opinions can be observed among my interview partners, whereas most of them advocate the inclusion of small-sized entrepreneurs.

On the one hand, the majority of the interviewees are convinced that small-sized entrepreneurs, such as peasants and fishermen, can benefit from the emerging technology as well (IP3: 6; IP4: 72; IP6: 42; IP7: 8; IP9: 6). As IP9 (6) clarifies: "the system is suitable for smallholders with restricted or no access to the internet as well since the system is steadily refined and tailored according to their needs." She further clears that blockchain adoption does not depend on the company size. Instead, the purpose of integrating blockchain should be properly evaluated. Adopting blockchain can enhance trust, no matter what stage a company is positioned along a supply chain. Thus, trust is not only important for end consumers, but for other actors of a supply chain as well (IP9: 14). IP4 (72) also believes that small-scale fishermen can take advantage of this technology. In the case that fishermen are selling premium fish, they can provide proof of their quality, which in turn enables them to access high value markets. This is also the case for famers that offer organic products, while they can additionally assure that their suppliers of seedlings and roughage had complied with their requirements (IP9: 15).

On the other hand, there is a blockchain solution provider (IP5: 56-58) who states that the technology does not attract very small producers due to its required investment costs. Hence, a funding third party or a powerful player within a supply chain normally initiates such blockchain-enabled systems (IP5: 56-58). Yet, he assumes that this will change in the near future as they are developing blockchain solutions that can be partly designed in a self-service manner and thus offering it at lower costs. For another blockchain provider (IP6: 42), it is key to offer affordable and simple blockchain solutions with the aim that small-sized companies can adopt the emerging technology as well.

The case study of Provenance (2016) explicitly promotes the inclusion of local fishermen who sustainably catch tuna with the pole and line method in Indonesia. Since 3G and Wi-Fi access can be patchy in some areas and assuming that every fisherman has a mobile phone, they can simply send an SMS message to register their catch. To clarify the spatial and technical circumstances, 3G has a maximum distance range of ten kilometers, while Global System for Mobile Communications (GSM) supports signal for sending SMS up to 35 kilometers (Seemann 2012). Thus, within the proximity of land, a digital twin is created on the blockchain by simply sending an SMS. Eventually, the digital twin will be transferred to the supplier once the tuna is physically handed over. This may be an appropriate solution for coastal fisheries. When it comes to pelagic fisheries (fisheries on the open sea), however, satellite communication is required to transmit data, which is not feasible for fisheries with limited financial resources (Blaha and Katafono 2020: 15).

The just mentioned case study of Provenance (2016) in Indonesia evokes the next question whether blockchain is suitable for developing countries as well. Taking into account that 80 percent of the global fish is sourced in waters of the Global South, these countries are key players in the global fish production (Campling, Havice, and Mccall Howard 2012: 187). However, actors in developing states are increasingly struggling to capture greater gains from the value chain due to global capitalism. Leading retailers compete horizontally for market share by attracting consumers with lower prices in the Global North, whereby reduced revenues result for fisheries from the Global South (Havice and Campling 2013: 2617). Yet, local fisheries are critical to food security and livelihoods in coastal communities (Campling et al. 2012: 187). Thus, given that both chains - blockchains and food supply chains - are global in nature, all actors of the value creation process must be included (IP7: 18). Therefore, it is crucial to design blockchain technology in a participatory and inclusive manner that gives its stakeholders incentives to participate (IP5: 68). According to IP5 (68), “either the producers or the retailers are the ones that profit the most.” He justifies this statement as retailers gain a marketing instrument with blockchain that promotes sustainable practices, while producers may capture a larger share of the value chain.

On behalf of smallholders in the Global South, AgUnity, a blockchain-based startup, designed the blockchain-based mobile application AgriLedger. Its goal is to empower smallholder farmers in developing countries by simplifying their access to global markets and mitigate production inefficiencies. Similar to the aforementioned example of Provenance, farmers can tokenize their assets on the blockchain with their mobile phone. Using the application, farmers can trade their products directly with other farmers or suppliers at fair prices. This allows them to retain a bigger share of the value chain, leading to increased income by two to three times. Furthermore, it is planned that micro-loans will be enacted via the AgriLeger application (Murthy et al. 2019: 3-6).

However, there is a digital gap between developed and developing countries in terms of different levels of computerization. This obstacle is difficult to overcome by smallholders to participate in blockchain-enabled supply chains (Kamilaris et al. 2019: 649). AgUnity tries to fill this digital gap by providing smallholders with cheap smart phones and other needed infrastructure on loan. In addition, the software comes in a simple design and is aimed at users with low levels of literacy, while no pre-knowledge of smart phones is required. Thus, according to AgUnity, they address global poverty alleviation by empowering smallholders in rural and remote communities worldwide (AgUnity 2018).

6.2.3 Making sustainability food labels redundant?

Sustainability labels (e.g., RSPO, Fairtrade, Marine Stewardship Council (MSC)) are important tools to enable conscientious consumption (Provenance 2015). They define standards and rules for responsible production practices (FAO 2018b: 151). Hence, ecolabels can be regarded as ethical representatives that determine what practices are considered as sustainable (IP4: 90).

Currently, chain of custody (CoC) certifications are issued through annual audits that typically entail on-site inspections, sample controls and employee interviews. Therefore, its audits are time and money consuming, while its detection for fraud and error is amendable due to the high volumes being produced and traded (Rosencrance 2017). The recent case of Ikea and the timber certifier Forest Stewardship Council (FSC) illustrates this malfunction. FSC is accused to certify illegal wood from Ukrainian forests, which was enabled through corrupt FSC's auditors (Earthsight 2020). Regardless whether the accusations will come true, its resulting media echo puts on both parties a dubious reputation.

In recent years, a proliferation of ecolabels has been observed, offering a greater choice for consumers. These multiple schemes, on the other hand, have led to confusion among retailers and consumers. Many retailers are not in the position to assess whether all the production criteria have been met, while many consumers are not aware about the underlying principles and requirements of ecolabels (FAO 2018b: 151; IP4: 90). Hence, its actual meanings are difficult to fully understand, while its verification of ethical practices poses a challenge, which is particularly the case in regions with high levels of corruption (Provenance 2015).

Even though blockchains cannot replace ecolabels they can underpin their credibility (IP1: 73). By providing a higher level of transparency and making crucial information accessible to end consumers, an additional layer of trust is created for sustainability labels, making them more trustworthy. This is crucial since according to IP9 (17), "trust is the groundwork of every ecolabel."

The fact is that ecolabels, such as FSC, RSPO and MSC just started to discover the added value enabled through blockchain to improve their credibility (IP5: 60). Since blockchain can help to prove how a product has been sourced and processed, the technology can also assure that products are aligned with other production claims (see section *5.4.2* for these claims).

A blockchain solution provider (IP6: 100-102) goes one step further and is convinced that a blockchain-trustable label will be introduced that shows consumers that certain standards along a supply chain had been monitored with blockchain technology. Thus, a higher level of confidence in blockchain-based products among consumers could be realized.

6.3 Synthesis of end user experience and internal supply chain traceability

This section compares and assesses the two main blockchain-based use cases of end user experiences due to public verifiability and the traceability system for internal process optimizations along supply chains.

In the beginning of this master thesis, my motivation was to show how blockchain technology can improve transparency of food production for end consumers as most food chains are opaque and difficult to understand, while the production of some commodities (e.g., tuna) is ethically critical.

Offering such a public verifiability can promote sustainable sourcing and production, while awareness about ethical issues is raised. At the same time, a responsible consumption is promoted. However, based on the statements of my interviewees and when analyzing existing blockchain-based use cases, I critically question its well-intentioned goal at the present time. As long as widespread trustworthy verification mechanisms are missing that address the first-mile problem and human interactions continue to add data manually to the blockchain, consumers cannot fully trust the data, which undermines the logic behind blockchain (IP1: 45). Furthermore, there is the common perception that some retailers deploy blockchain with the main motivation to trigger press releases, which offers them an effective marketing instrument to gain public attention and positions themselves as innovative forerunners. Finally, the usability of tracking products with a QR code and an imprinted log number is strongly amendable. Reading and typing the difficult legible lot number on products packages is cumbersome and discourages consumers to track items. Hence, consumer-facing apps need to be developed that are more user-friendly and interoperable with a greater variety of food products.

However, regardless of the direct outcome of blockchain, it does raise environmental awareness among consumers to some extent. In this sense, a quote of IP8 (142) exemplifies this desire: "the fact is that blockchain creates more attention and interest […], if people have more attention to our traceability it's already great."

On the other hand of this synthesis, there are blockchain-enabled traceability systems for optimizations of internal processes within food supply chains. Here, the quality of the entered data to the blockchain is of less importance, while improved collaboration and efficiency gains are priorities. Digitalizing supply chains with immutable distributed ledgers offers several advantages for food companies and retailers, including various efficiency gains, reduced costs, enhanced security, and improved food safety due to faster product recalls. Collaboration between actors in a supply chain is improved through digital communication, which gives them more flexibility in the logistics management. Thereby, smart contracts play a key role and present huge room for further development that will increasingly automatize supply chain processes. Furthermore, collecting and analyzing data becomes increasingly more important and is crucial for managing supply chains through which the sourcing and production can be realized more efficiently. When considering these drivers, an improved governance of food supply chains can be realized, implying a top-down approach as described in the GVC framework of Gereffi and Lee (2012). Thus, it comes as little surprise that several leading food companies (e.g., Walmart, Nestlé, Migros) have deployed blockchain to improve their internal SCM. Integrating blockchain in SCM could also help carrying out due diligence as responsible companies can provide proof that they complied with standards. Thus, blockchain could become a helpful tool regarding the Responsible Business Initiative as proposed in Switzerland.

It seems that internal company tracking is at least as important as enabling end user experiences (IP1: 31). This, in particular, becomes apparent when comparing the benefits of end user experience applications and the ones for internal SCM tracking. A blockchain integration for the latter purpose offers many more advantages, whereby inefficiencies and cost reductions can be directly realized, which constitute major economic drivers for the retailing industry. At this point, however, it is notable to mention that blockchain-enabled supply chains without public verifiability do not directly address any environmental sustainability issues. Instead, they are usually deployed due to economic reasons. Yet, IP4 (102) sees exactly this factor to be decisive for widespread adoption: “it [blockchain] will only assert itself if economic savings can be realized.” Due to this reason, I assess that blockchain-enabled internal traceability systems have a greater potential to reach widespread usage in the food industry than blockchains that solely serve for public verifiability.

Finally, I want to emphasize the desire to offer public verifiability for end consumers when blockchain is deployed for internal SCM improvements since most of the infrastructure to provide such information is already provided. Such a trend could substantially raise awareness about global sustainable issues among consumers, while an ethical production and consumption are promoted.

6.4 Future of blockchain in food supply chains

This section presents an outlook regarding blockchain technology in food supply chains. Yet, it is difficult to provide a detailed outlook as the blockchain’s future applications remain highly uncertain (IP3: 8; IP4: 102).

The fact is however, that the food industry has just started using blockchain, whereby its true potential is being explored (IP1: 35). The interest in the technology is huge and there will be a proliferation of blockchain-based applications in the food industry within the next five years (IP1: 121, 125; IP5: 92; IP6: 70, 90; IP8: 130). However, there will be a great percentage of companies that will not go beyond the pilot stage as they will not see any added value for their business cases. Once the true potential of blockchain is understood, there will be some cases that will prove its advantages and persist to exist, though (IP1: 125).

Two blockchain providers (IP5: 82, 92; IP6: 74, 90) are convinced that blockchain will become a norm in the food industry within the next five years. As IP6 (74) states: “in some years, if your food [food offered by a retailer] is not trustable on a blockchain, you will have some issues with your customers because it shows that you are not totally transparent.” IP8 (131) perceives blockchain technology more critically and does not believe that the technology will become a standard in the food industry. Nor does she support the premise that data is more reliable due to blockchain as an effective verification of the entered data is missing. Yet, she admits great potential for the management and analysis of data (ibid: 31). Finally, she perceives blockchain as potentially revolutionary when smart contracts are integrated, whereby sustainability concerns along food chains could be diminished (ibid: 45). IP7 (44) believes that blockchain will be one of many components for future supply chains. Yet, its full establishment will take time. If blockchain-based systems will not provide any substantial added value and will not reach widespread usage by 2025, she thinks that the technology will dilute over time.

Furthermore, there is strong evidence that the food industry is going towards permissioned blockchains instead of permissionless. Privacy and the disclosure of sensitive information remain serious concerns. Moreover, there is a trend that the blockchain-enabled internal SCM tracking will be increasingly realized. This becomes particularly clear when comparing the benefits of end user experience applications and the internal SCM tracking. A blockchain integration for the latter purpose offers many more advantages since inefficiencies and cost reductions are directly addressed, which constitute major economic drivers for the retailing industry.

When considering the use case of AgUnity and assuming that smallholders can substantially benefit from blockchain-based solutions, blockchain can provide an unprecedented instrument to meet the SDGs in a number of areas posed by the FAO. In this sense, blockchain can be regarded as an upgrading strategy as described in the GVC framework by Gereffi and Lee (2012).

Yet, blockchain’s outcomes remain uncertain as it also offers the opportunity to support malicious activities, when the technology is abused. In case of such a disclosure, the technology’s reputation will severely suffer as its purpose remains questionable.

Finally, it is important to mention that transparency and traceability issues throughout supply chains can be addressed with other technologies as well. Blockchain does not solve every problem at hand. However, it is a further step towards more transparency and more information in a highly globalized world (IP9: 28).

7 Conclusion

This master thesis assessed and analyzed the true potential of blockchain technology within food supply chains. For this, nine interviews were conducted with experts that either hold profound knowledge regarding blockchain or are key actors in the food industry. Their arguments are supported and complemented by external sources such as academic literature, news articles and reports from key organizations.

In the conclusion, the findings of the content analysis are summarized, giving answers to the three research questions. Thereby, each of the following three sections addresses its respective research question, which are now recapped: *How does blockchain technology assist food supply chains and who are the beneficiaries? What are the remaining challenges around blockchains in the food industry and how could they be addressed? To what extent can the blockchain technology transform the food industry?*

Finally, limitations of this work are discussed and an outlook regarding future scopes of works is provided.

7.1 Findings: Opportunities and beneficiaries of blockchain

The main advantage of blockchain technology is the tamper-proof storage of data, which this thesis fully approves. Due to the decentralized design of blockchain, there is no single point of failure in the system created, making the network more resilient and thus tamper-proof against subsequent manipulation of data. However, blockchain does not improve the quality of input data as widespread verification mechanisms are missing. Malicious actors in the network can be identified and if necessary be sanctioned, though. This feature in turn, increases trust among the network's participants. Furthermore, this work identified two main reasons why blockchain is applied within food supply chain.

The first reason comprise that supply chains are made visible to end consumers for public verifiability. To enable such end user experiences, public permissioned blockchains are usually deployed. Thereby, consumers can verify where, how and when their products had been sourced and processed. Giving consumers access to this information, allows them to make informative purchase decisions that are aligned with their own values. Be it claims for sustainable, organic, allergy-free, or non-GMO products, blockchain can provide proof of origin and its production methods. So far, blockchain with public verifiability is mostly applied for high value commodities whose sourcing may be critical. By providing consumers with such crucial information, a consumer empowerment is facilitated, which exerts pressure on retailers. This leads to improved sustainable production practices as retailers dictated production methods and conditions. Thereby, unethical and illegal practices such as modern-day slavery and IUU fishing can be mitigated. Providing such information about products' sourcing methods can gain momentum and galvanize a change in consumer behavior towards a more sustainable consumption. Hence, blockchain has the potential to rewrite the rules for a sustainable and ethical production and consumption. A driver for retailers to enable such public verifiability is to demonstrate their superior quality, which fosters customer loyalty. This in turn gives them competitive and marketing arguments.

The second and more evident reason why blockchain is applied within the food sector is to improve processes and traceability within supply chains. Thereby, permissioned blockchains are usually deployed, while the consortium blockchain is of particular interest. Digitalizing record bookkeeping enabled by blockchain enhances efficiencies along supply chains, while unprecedented real-time monitoring of production is facilitated. Such an improved traceability system allows retailers and other food companies to fulfill dynamic storage management requirements and thus a flexible management of logistics throughout supply chains is facilitated. In case of immediately needed product recalls (e.g., product contamination), food companies can react faster and thereby contribute to food safety. Additionally, using smart contracts, several further advantages are created due to a higher level of automatization. Complying with food safety regulations becomes easier as storage conditions are monitored with IoT-enabled devices. Changes in custody can also be automatically registered with smart contracts. This feature makes blockchain an appropriate tool for complex supply chains and for perishable commodities whose cold chains need to be monitored. Furthermore, blockchain has the potential to make intermediaries redundant, speeding up transactions, while reducing costs. Since blockchains provide an immutable and tamper-proof recording of data, food fraud and other illicit activities (e.g., subsequent dilution with non-certified products or corruption) can be mitigated. This in turn increases trust because all participants of a network have a copy of the same ledger. Thus, each actor can verify the transactions of each other. Finally, deploying a blockchain within food supply chains can also be a marketing instrument for retailers as it provokes press releases that portray them as innovative forerunners.

Blockchain can be an advantage not only for large corporations, but also for small-sized companies and smallholders. By providing proof of their products' quality, trust can be enhanced in smallholders' products. This, in return, improves their access to global markets, which is particularly worthwhile for premium commodities that comply with high standards (e.g., organic products).

Due to these findings, the beneficiaries of blockchain integration into food supply chains are retailers, responsible producers, and empowered consumers. Of course, retailers are the main beneficiaries as they profit from increased sales and cost reductions due to higher efficiency throughout the supply chain. In addition, deploying blockchain can also be an effective instrument for companies that want to prove that they complied with certain standards and laws. Thus, blockchain could become increasingly important in respect of responsible corporations when they are obliged to carry out due diligence. Furthermore, responsible producers can provide proof of their production methods, thus helping them to obtain access to high value chains. Finally, consumers benefit from enhanced transparency enabled through blockchain, whereby a consumer empowerment can be promoted.

7.2 Findings: Challenges and solutions

Despite of all the benefits several challenges around blockchain in the food supply chain remain unresolved. To some of these challenges feasible solutions are provided in this thesis.

A substantial hurdle poses the lack of knowledge regarding blockchain technology among entrepreneurs, producers, and consumers. Given the technical complexity of the technology, it takes a lot of effort to convince companies how blockchain can provide an added value to their businesses. Instead, many actors prefer to work with established technologies. Integrating blockchain in their existing systems, such as complex ERP-systems, poses the risk of failure, whereby the production may come to a halt. Since there are only limited blockchain-enabled cases in the food industry and most of them are in the pilot stage, the technology needs to mature. For this, education and trainings need to be conducted that teach how blockchain-enabled projects can be adequately realized. Thereby, an exchange of knowledge regarding blockchain is strongly promoted, which helps other stakeholders to realize successful blockchain-based projects.

The lack of standard regulatory frameworks represents another challenge. Since most blockchain solutions are developed in digital information silos, interoperability standards and a common language are missing that allow to flawlessly connect with the systems of other actors along supply chains. Therefore, there is a strong need to elaborate data standardization for a successful collaboration throughout supply chains. Such a standardization is also advisable from the consumer perspective as consumers would no longer need several different tracing applications on their mobile phone to track products from different retailers. Although the retailing industry is still far away from reaching such a standardization, ISO and GS1 are committed to elaborate the needed standards. Both organizations work on standardized process, while the latter organization focuses on interoperable traceability standards for the unique identification of items.

A far-reaching issue constitutes the interface between the physical and the digital world. Specifically, the fist-mile problem remains a serious concern. The problem at hand is the verification of the data entering the blockchain. The integrity of the blockchain is only as good as the quality of the data. Hence, it is important to verify that the entering data is true. As illustrated by the real example in the fishing industry, a solution is provided that identifies IUU fishing in illegal waters. In this case, machine learning algorithms are fed with GPS data and actual fishing conditions (vessel's speed, depth of the ocean and weather conditions), whereby irregularities are detected in the data. However, every system and device could still be tampered, leaving loopholes for malicious activities.

Furthermore, when choosing the appropriate type of blockchain for a business case, a tradeoff between transparency and privacy seems inevitable. Full transparency may improve collaboration, but sensitive information is disclosed to other actors. This cleavage is the reason why many entrepreneurs resist to participate in transparent blockchains. In permissioned blockchains, though, actors can decide what information is visible to other stakeholders.

It seems that the investment costs of setting up a blockchain is a smaller burden. Compared to other traceability software, blockchain-enabled traceability systems are inexpensive, while costs are expected to decrease with progressing blockchain deployments. A challenge thereby remains, how costly IoT devices are integrated for low value commodities. In addition, the high costs still constitute a barrier for small-sized companies or entrepreneurs from the Global South. Yet, their inclusion is mandatory to provide a complete history of many products.

Finally, there are also technical constraints regarding blockchain in food supply chains. Scalability is particularly a challenge for public blockchains that are applied for complex supply chains as they can only handle limited transactions. In comparison, private blockchains can handle more data. Yet, there are several efforts going on to improve scalability in blockchain-based systems. Moreover, there are concerns about the blockchain's security. Tampering with private blockchains that consist of few nodes makes them vulnerable to malicious activities. Public blockchains are more secure due to its high number of nodes in the decision-making process. Blockchain's nature of storing data immutably creates several advantages. However, its pitfall is that incorrect data by mistake cannot be reversed.

At present, the high power consumption for the PoW consensus mechanism, which is deployed in most public blockchains, constitutes a serious environmental concern. This issue is expected to be overcome in the long-term, though. More power efficient mechanisms, such as PoS are on the rise, that might replace PoW mechanisms. On the other hand, private blockchains normally use PoA or PBFT protocols that need less computational power for the consensus mechanisms, thus constituting a smaller concern for internal supply chain tracking.

7.3 Findings: Transformations within food supply chains

Although in most literature, blockchain is regarded as a disruptive technology, the majority of my interview partners do not share this opinion. However, some transformations in the food supply chain are expected by some interviewees. Disintermediation and thus reduced costs for managing food supply chains were the most mentioned changes brought by blockchain. Thereby, smart contracts will play a key role as they facilitate a higher level of automatization. Moreover, a shift of employment from routine works towards more strategic job positions is expected. Thus, a reskilling of human workforce will be inevitable, which is already a key factor posed by the ongoing digitalization. Yet, this process will be a challenging endeavor, while developed countries may benefit disproportionately from automatized systems. Evidently, jobs will be created in the blockchain-related solution sector, though. On the other hand, most interviewees regard disintermediation as a relentless process, regardless of blockchain-enabled systems. Yet, as long as intermediaries offer an added value, they will not be excluded from food supply chains.

If harnessed in the right way, blockchain can be an advantage not only for large corporations, but also for small-sized companies and smallholders. By providing proof of their products' quality, trust can be enhanced in smallholders' production. This in return improves their access to global markets.

In addition, there are some blockchain-based projects that explicitly promote the inclusion of smallholders in developing countries. Thus, producers can retain a larger share of the value chain by trading their products at fairer prices. Thereby, an empowerment of smallholders in developing countries can be achieved. At the same time, asymmetric power relations along global supply chains can be diminished, while social inequalities between the Global South and North can be reduced.

Another interesting field where blockchain can provide an added value is the safeguarding of standards for issuing ecolabels. Since trust is the groundwork of every ecolabel, blockchain can create an additional layer of trust, whereby crucial information is transparently communicated to end consumers. Even though blockchain cannot replace ecolabels, they can significantly underpin their credibility by providing proof that certain standards have been met. Eventually, a new blockchain-label could be introduced, which implies that a commodity's supply chain was monitored and managed with blockchain technology. Such a blockchain label could increase the awareness about the technology and trust among consumers towards a product's provenance.

Despite all of the promises offered by blockchain, there is also the risk of abusing the technology. Malicious actors could take advantage of the enhanced transparency and data aggregation enabled through blockchain. For example, the identity of key players within auditing processes are disclosed, which helps malicious actors to systematically identify and bribe auditing stakeholders in order to overexploit natural resources.

7.4 Outlook

Given the limited scope of this thesis, several relevant topics have not or only scarcely been discussed. A central purpose of this thesis is to identify remaining challenges regarding blockchain applications and to inspire other researchers to conduct research that aim to address these remaining issues. Furthermore, not all stakeholders of a food supply chain have been involved in this work. Hence, I suggest further research in other fields.

First, there was only one interview partner representing the retailing industry, which sets strong limitations regarding the significance of how the retailing sector perceives the benefits, disadvantages and challenges posed by blockchain technology. Thus, I suggest doing according research that involves a larger sample of retailers.

Second, this work did not involve any producing stakeholders such as farmers and fisheries. Their inclusion is essential for a proper assessment of the impacts on all involved stakeholders of a supply chain. Therefore, I strongly suggest research that assesses the true benefits and challenges for producers introduced by blockchain. Such an approach is helpful as smallholders could benefit from gaining larger shares from global value chains. Therefore, blockchain-enabled projects that involve smallholders from the Global South and North should be evaluated. Thereby, it can be assessed to what extent blockchain might help mitigating inequalities by empowering smallholders and alleviating globally occurring poverty at the same time.

Third, it is not yet clear, to what extent blockchain-enabled transparency is demanded by consumers and to what extent they trust data stored on the blockchain. In this sense, assessing the acceptance of blockchain among consumers is helpful as potential trust issues can be identified and accordingly addressed. For this, a quantitative approach could shed light on the consumers' acceptance and perception regarding blockchain in food supply chains.

Fourth, this work marginally discussed the potential impacts on certifying food ecolabels. Yet, I believe that blockchain can significantly support the credibility of such ecolabels. Hence, further research is suggested that assess the benefits and challenges of blockchain-enabled traceability systems for ecolabels.

Finally, further research on blockchain-based projects with smart contracts, IoT, big data and AI is useful as the potential benefits are vast. Many challenges remain unclear regarding the implementation of smart contracts since they need to mature until widespread adoption is reached in the food industry. Thereby, regulating frameworks should be considered that discuss the legal binding of smart contracts and AI-induced activities.

8 Literature

Adolf, S., Bush, S. R., and Vellema, S. 2016. “Reinserting State Agency in Global Value Chains: The Case of MSC Certified Skipjack Tuna.” *Fisheries Research* 182:79–87.

Agnew, D. J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J. R., and Pitcher, T. J. 2009. “Estimating the Worldwide Extent of Illegal Fishing.” *PLoS ONE* 4(2).

AgUnity 2018. “How it works. Available at: https://www.agunity.com/how-it-works (retrieved on 8 October 2020).

Al-Saqaf, W. and Seidler, N. 2017. “Blockchain Technology for Social Impact: Opportunities and Challenges Ahead.” *Journal of Cyber Policy* 2(3):338–54.

De Angelis, S., Aniello, L., Baldoni, R., Lombardi, F., Margheri, A., and Sassone, V. 2018. “PBFT vs Proof-of-Authority: Applying the CAP Theorem to Permissioned Blockchain.” *CEUR Workshop Proceedings* 2058:1–11.

Angrish, A., Craver, B., Hasan, M., and Starly, B. 2018. “A Case Study for Blockchain in Manufacturing: ‘FabRec’: A Prototype for Peer-to-Peer Network of Manufacturing Nodes.” *Procedia Manufacturing* 26:1180–92.

Attaran, M. and Gunasekaran, A. 2019. *Applications of Blockchain Technology in Business: Challenges and Opportunities*.

Aung, M. M. and Chang, Y. S. 2014. “Traceability in a Food Supply Chain : Safety and Quality Perspectives.” *Food Control* 39:172–84.

Azzi, R., Chamoun, R. K., and Sokhn, M. 2019. “The Power of a Blockchain-Based Supply Chain.” *Computers and Industrial Engineering* 135(August 2018):582–92.

Baker, A. 2018. “Blood diamond.” *Time.com*. Available at: https://time.com/blood-diamonds/ (retrieved on 6 July 2020).

Bailey, M, Bush, S. R., Miller, A., and Kochen, M. 2016. “The Role of Traceability in Transforming Seafood Governance in the Global South.” *Current Opinion in Environmental Sustainability* 18:25–32.

Banerjee, A. 2017. “Integrating Blockchain with ERP for a Transparent Supply Chain.” *Infosys*.

Banker, S. 2018. “Blockchain Gains Traction in the Food Supply Chain”. *Forbes*. Available at: https://www.forbes.com/sites/stevebanker/2018/07/25/blockchain-gains-traction-in-the-food-supply-chain/#355fe2c1cf95 (retrieved on 7 July 2020).

Bano, S., Sonnino, A., Al-Bassam, M., Azouvi, S., McCorry, P., Meiklejohn, S., and Danezis, G. 2017. “Consensus in the Age of Blockchains.”

Blaha, F. and Katafono, K. 2020. *Blockchain Application in Seafood Value Chains*. Vol. 1207.

Blockchain Consensus Encyclopedia 2020. Available at: https://tokens-economy.gitbook.io/consensus/ (retrieved on 8 May 2020).

Bogner, A. and Menz, W. 2002. “Das theoriegenerierende Experteninterview. Erkenntnisinteresse, Wissenformen, Interaktion.” In: Bogner, Alexander, Littig, Beate, and Menz, Wolfgang (PUB): Das Experteninterview. Theorie, Methode, Anwendung. *Springer Fachmedien Wiesbaden GmbH*, 33: 33-70.

Busch, L. 2007. “Performing the Economy, Performing Science: From Neoclassical to Supply Chain Models in the Agrifood Sector.” *Economy and Society* 36(3):437–66.

Bünger, M. 2017. “Blockchain for industrial enterprises: Hype, reality, obstacles and outlook.” *IoT Agenda*. Available at: https://internetofthingsagenda.techtarget.com/blog/IoT-Agenda/Blockchain-for-industrial-enterprises-Hype-reality-obstacles-and-outlook (retrieved on 17 May 2020).

CAC 2006. “Principles for Traceability/Product Tracing as a Tool within a Food Inspection and Certification System.” *Cac/Gl 60-2006* 1–4.

Chandler, S. 2019. “What Is the Difference Between Blockchain and DLT?” Availabe at: https://cointelegraph.com/news/what-is-the-difference-between-blockchain-and-dlt (retrieved on 23 November 2019).

Campling, L. 2016. “*The Global Value Chain in Canned Tuna, the International Trade Regime and Implementation of Sustainable Development Goal 14*”. International Trade Working Paper.

Campling, L., Havice, E., and Mccall Howard, P. 2012. “The Political Economy and Ecology of Capture Fisheries: Market Dynamics, Resource Access and Relations of Exploitation and Resistance.” *Journal of Agrarian Change* 12(2–3):177–203.

Carrefour 2020. “Carrefour applies blockchain technology to Carrefour Quality Line salmon.” Available at: https://www.carrefour.com/en/newsroom/carrefour-applies-blockchain-technology-carrefour-quality-line-salmon. (retrieved on 31 July 2020).

Casado-Vara, R., Prieto, J., De La Prieta, F., and Corchado, J. M. 2018. “How Blockchain Improves the Supply Chain: Case Study Alimentary Supply Chain.” in *Procedia Computer Science*. Vol. 134.

Casino, F., Dasaklis, T. K., and Patsakis, C. 2019. “A Systematic Literature Review of Blockchain-Based Applications: Current Status, Classification and Open Issues.” *Telematics and Informatics* 36(November 2018):55–81.

Chang, Y., Iakovou, E., and Shi, W. 2020. “Blockchain in Global Supply Chains and Cross Border Trade: A Critical Synthesis of the State-of-the-Art, Challenges and Opportunities.” *International Journal of Production Research* 58(7):2082–99.

Charlebois, S., Sterling, B., Haratifar, S., and Naing, S. K. 2014. “Comparison of Global Food Traceability Regulations and Requirements.” *Comprehensive Reviews in Food Science and Food Safety* 13(5):1104–23.

Chou, S. 2019. “THE FOURTH INDUSTRIAL REVOLUTION: DIGITAL FUSION WITH INTERNET OF THINGS.” *Journal of International Affairs* 72(1):107–20.

Cole, R., Stevenson, M., and Aitken, J. 2019. “Blockchain Technology: Implications for Operations and Supply Chain Management.” *Supply Chain Management* 24(4):469–83.

Cook, B. 2018. "Blockchain: Transforming the Seafood Supply Chain." 1–41. *WWF NZ*. Available at: https://dj8xp7a0ejkvv.cloudfront.net/downloads/draft_blockchain_report_1_4_1.pdf (retrieved on 21 July 2020).

Coote, R., Nevile, C., Noble, G., and Polzer, G. 2020. "Enterprise Ethereum Alliance Client Specification V5." (October):1–68.

Corporate Justice 2018. "About the Initiative." Available at: https://corporatejustice.ch/about-the-initiative/ retrieved on (20 September 2020).

Dauvergne, P. and Clapp, J. 2016. "Researching Global Environmental Politics." *Global Environmental Politics* 16(1):1–12.

Deloitte 2019. "Deloitte ' s 2019 Global Blockchain Survey Blockchain Gets down to Business." *Deloitte Insights* 2–48.

Díaz, A. and Grau Ruiz, M. A. (2020). "Social Security and robotization: Possible ways to finance human reskilling and promote employment." *Paladyn (Warsaw),* 11(1), 340-350.

Drath, R. and Koziolek, H. 2015. "Industrie 4.0 - Im Spannungsfeld Zwischen Dem Machbaren Und Sinnvollen." *Atp Edition* 1–2(1–2):28–35.

Earthsight 2020. FLATPÅCKED FÖRESTS. IKEA's illegal timber problem and the flawed green label behind it. Available at: https://www.earthsight.org.uk/flatpackedforests-en (retrieved on 18 September 2020).

European Parliament. 2013. Report on the food crisis, fraud in the food chain and the control thereof (2013/2091(INI)). Committee on the Environment, Public Health and Food Safety. A7-0434/2013.

Everledger n.d.. "Everledger and Gübelin." Available at: https://www.everledger.io/case-study/everledger-and-gubelin/?submissionGuid=38b3ad55-ae64-4ffc-b010-5f4efedaefee (retrieved on 15 July 2020).

EZ Lab 2020. "Wine blockchain." Available at: https://www.ezlab.it/case-studies/wine-blockchain/ (retrieved on 31 July 2020).

FAO 2018a. *The Future of Food and Agriculture - Alternative Pathways to 2050.* Summary Version. Food and Agriculture Organization.

FAO 2018b. T*he State of World Fisheries and Aquaculture 2018 - Meeting the Sustainable Development Goals.* Food and Agriculture Organization.

FAO 2019. *The State of Food and Agriculture 2019. Moving Forward on Food Loss and Waste Reduction.* Food and Agriculture Organization.

FAO and ITU 2019. *E-Agriculture in Action: Blockchain for Agriculture Opportunities and Challenges.* Food and Agriculture Organization.

Furlonger, D. and Kandaswamy, R. 2019. "2019 CIO Agenda: Blockchain's Emergence Depends on Use Cases." (June).

Furlonger, D. and Uzureau, C. 2019. “The real business of blockchain: How leaders can create value in a new digital age.” *Boston Massachusetts: Harvard Business Review Press.*

Gaehtgens, F. and Allan, A. 2017. “Digital Trust — Redefining Trust for the Digital Era : A Gartner Trend Insight Report What You Need to Know.” *Gartner Report* (May):1–8.

Galvez, J. F., Mejuto, J. C., and Simal-Gandara, J. 2018. “Future Challenges on the Use of Blockchain for Food Traceability Analysis.” *TrAC - Trends in Analytical Chemistry*.

Garrod, J. Z. 2019. “On the Property of Blockchains: Comments on an Emerging Literature.” *Economy and Society* 48(4):602–23.

Gartner 2019. “Gartner 2019 Hype Cycle Shows Most Blockchaintechnologie Are Still five to 10 Years Away From Transformational Impact.” *Gartner.* Available at: https://www.gartner.com/en/newsroom/press-releases/2019-10-08-gartner-2019-hype-cycle-shows-most-blockchain-technologies-are-still-five-to-10-years-away-from-transformational-impact (retrieved on 14 August 2020).

Gereffi, G. 1994. “The Organization of Buyer-Driven Global Commodity Chains: How US Retailers Shape Overseas Production Networks.” *Commodity Chains and Global Capitalism*, 43–71.

Gereffi, G. and Fernandez-Stark, K. 2011. “Global Value Chain Analysis: A Primer.” *Handbook on Global Value Chains* (May 2011):54–76.

Gereffi, G., Humphrey, J., and Sturgeon, T. J. 2001. “Introduction: Globalization, Value Chain an Development.” *IDS Bulletin* 32(3):1–8.

Gereffi, G. and Lee, J. 2012. “Why the World Suddenly Cares About Global Supply Chains.” *Journal of Supply Chain Management* 48(3):24–32.

Gibbon, P. and Ponte, S. 2005. “Entry Barriers, Marginalization, and Upgrading. In Trading Down: Africa, Value Chains, And The Global Economy.” *Philadelphia: Temple University Press* 125–60.

Gopi, K., Mazumder, D., Sammut, J., and Saintilan, N. 2019. “Determining the Provenance and Authenticity of Seafood: A Review of Current Methodologies.” *Trends in Food Science & Technology* 91:294–304.

Graham, M. 2019. *Digital Economies at Global Margins*. London, England: MIT Press.

Groenfeldt, T. 2017. "IBM and Maersk apply blockchain to container shipping." *Forbes.* Available at: https://www.forbes.com/sites/tomgroenfeldt/2017/03/05/ibm-and-maersk-apply-blockchain-to-container-shipping/?sh=f5e89c13f05e#154325c43f05 (retrieved on 25 July 2020).

GS1 2019. “Traceability and Blockchain.” *GS1*. 1–8.

Havice, E. and Campling, L. 2013. “Articulating Upgrading: Island Developing States and Canned Tuna Production.” *Environment and Planning A* 45(11):2610–27.

Havice, E. and Campling, L. 2017. “Where Chain Governance and Environmental Governance Meet: Interfirm Strategies in the Canned Tuna Global Value Chain.” *Economic Geography* 93(3):292–313.

Helfferich, C. 2011. “Die Qualität Qualitativer Daten. Manual Für Die Durchführung Qualitativer Interviews. ” Vol. 58. *VS Verlag für Sozailwissenschaften.*

Hermann, M., Pentek, T., and Otto, B. 2016. “Design Principles for Industrie 4.0 Scenarios.” Pp. 3928–37 in *Proceedings of the Annual Hawaii International Conference on System Sciences*. Vols. 2016-March. IEEE.

Hirsch-Kreinsen, H. 2016. “Digitalisierung Industrieller Arbeit: Entwicklungspfade Und Perspektiven.” *Journal for Labour Market Research* 49(1):1–14.

Ho, D. C. K., Au, K. F., and Newton, E. 2002. “Empirical Research on Supply Chain Management: A Critical Review and Recommendations.” *International Journal of Production Research* 40(17):4415–30.

Horch, P. 2020. “Bitcoin, Schweine, Diamanten.” *BTC Echo.* Available at: https://www.btc-echo.de/bitcoin-schweine-diamanten/ (retrieved on 17 August 2020).

Hughes, A., Park, A., Kietzmann, J., and Archer-Brown, C. 2019. “Beyond Bitcoin: What Blockchain and Distributed Ledger Technologies Mean for Firms.” *Business Horizons* 62(3):273–81.

Hyperlegder 2019. “How Walmart brought unprecedented transparency to the food supply chain with Hyperledger Fabric.” Available at: https://www.hyperledger.org/learn/publications/walmart-case-study (retrieved on 31 July 2020).

Iansiti, M. and Lakhani, K. 2017. “The Truth about Blockchain. ” *Harvard Business Review* 95(1): 118-127.

ILO 2017. “Future of Work - Major trends: The deployment of industrial robots is rapidly intensifying, with the potential to change production processes worldwide.” *International Labour Organization*. Available at: https://www.ilo.org/global/topics/future-of-work/trends/WCMS_555548/lang--en/index.htm (retrieved on 19 November 2020).

IBM 2020. “CHO Taps IBM Food Trust to Provide Insight on Quality and Origin of Terra Delyssa Extra Virgin Olive Oil.“ Available at: https://newsroom.ibm.com/2020-01-14-CHO-Taps-IBM-Food-Trust-to-Provide-Insight-on-Quality-and-Origin-of-Terra-Delyssa-Extra-Virgin-Olive-Oil (retrieved on 31 July 2020).

IOE, ICC, and BIAC 2006. “Business and Human Rights : The Role of Business in Weak Governance Zones.” (December). Available at: https://media.business-humanrights.org/media/documents/files/reports-and-materials/Role-of-Business-in-Weak-Governance-Zones-Dec-2006.pdf (retrieved on 15 October 2020).

ITUNews 2018. “‘Food Trust’ partnership uses blockchain to increase food safety.” Available at: https://news.itu.int/food-trust-blockchain-food-safety/ (retrieved on 31 July 2020).

Jasperneite, J. 2012. “Industrie 4.0: Alter Wein in Neuen Schläuchen?” *Onkologe* 11(12):24–28.

Johannes 2020. “Blockchain für Lebensmittel: Freie Sicht auf Lieferketten?” *Lebensmittelmagazin*. Available at: https://www.lebensmittelmagazin.de/wirtschaft/20200214-blockchain-fuer-lebensmittel-freie-sicht-auf-lieferketten-industrie-handel/ (retrieved on 20 September 2020).

Jostock, M. 2019. “Blockchain in der Food Supply Chain.” *DLG-Expertenwissen.*

Kakavand, H., Kost De Sevres, N., and Chilton, B. 2017. “The Blockchain Revolution: An Analysis of Regulation and Technology Related to Distributed Ledger Technologies.” *SSRN Electronic Journal* 1–28.

Kamath, R. 2018. “Food Traceability on Blockchain: Walmart’s Pork and Mango Pilots with IBM.” *The Journal of the British Blockchain Association* 1(1):47–53.

Kamilaris, A., Fonts, A., and Prenafeta-Boldύ, F. X. 2019. “The Rise of Blockchain Technology in Agriculture and Food Supply Chains.” *Trends in Food Science & Technology* 91:640–52.

Kassner, K. and Wassermann, P. (2002). “Nicht überall, wo Methode draufsteht, ist auch Methode drin. Zur Problematik der Fundierung von ExperInneninterviews.” In: Bogner, A., Littig, B., and Menz, W. (PUB): Das Experteninterview. Theorie, Methode, Anwendung. *Springer Fachmedien Wiesbaden GmbH* 33: 95-111.

Kehoe, L., O’Connell, N., Andrzejewski, D., Gindner, K., and Dalal, D. 2017. “When Two Chains Combine: Supply Chain Meets Blockchain.” *Deloitte* 2–15.

Kim, M., Hilton, B., Burks, Z., and Reyes, J. 2018. “IoT to Design a Food Traceability Solution.” *2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)* (Figure 1):335–40.

Kshetri, N. 2017. “Will Blockchain Emerge as a Tool to Break the Poverty Chain in the Global South?” *Third World Quarterly* 38(8):1710–32.

Kshetri, N. 2018. “Blockchain’s Roles in Meeting Key Supply Chain Management Objectives.” *International Journal of Information Management* 39(June 2017):80–89.

Kuckartz, U. 2018. *Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung*. 4. Edition, Weinheim: Beltz Juventa.

Kuckartz, U. and Rädiker, S. 2019. *Analyzing Qualitative Data with MAXQDA*. Springer International Publishing.

Lambert, D. M. 2014. “Supply Chain Managment.” *Supply Chain Managment: Processes, Partnerships, Performance*, 1–22.

Lambert, D. M. and Cooper, M. C. 2000. “Issues in Supply Chain Management in Indian Agriculture.” *Industrial Marketing Management* 29:65–83.

Lambert, D. M. and Enz, M. G. 2017. “Issues in Supply Chain Management: Progress and Potential.” *Industrial Marketing Management* 62:1–16.

Lawrence, G. and Dixon, J. 2015. “The Political Economony of Agri-Food: Supermarkets.” in *Handbook of the International Political Economy of Agriculture and Food*. Cheltenham: E. Elgar.

Leitner, A. and Wroblewski, A. (2002). “Zwischen Wissenschaftlichkeitsstandards und Effizienzansprüchen. ExperInneninterviews in der Praxi der Arbeitsmarktevaluation.” In: Bogner, A., Littig, B., and Menz, W. (PUB): Das Experteninterview. Theorie, Methode, Anwendung. Opladen: Leske + Budrich, 241-256.

Lemieux, V. L. 2016. “Trusting Records: Is Blockchain Technology the Answer?” *Records Management Journal* 26(2):110–39.

Miller, R. 2019. “IBM-Maersk blockchain shipping consortium expands to include other major shipping companies.” Available at: https://techcrunch.com/2019/05/28/ibm-maersk-blockchain-shipping-consortium-expands-to-include-other-major-shipping-companies/ (retrieved on 13 July 2020).

Murthy, S. R., Hadzic, A., Roll, K., and Khalil, L. 2019. “Agriledger & Agunity.” (May).

Nakamoto, S. 2008. “Bitcoin Whitepaper: Ein Elektronisches Peer-to-Peer-Bezahlsystem.” *Www.Bitcoin.Org* 1(1):9.

Natarajan, H., Krause, S., and Gradstein, H. 2017. “Distributed Ledger Technology and Blockchain.” *Distributed Ledger Technology and Blockchain*.

Nestlé 2019. “Nestlé and Carrefour give consumers access to blockchain platform for Mousline purée.” Available at: https://www.reuters.com/article/us-carrefour-blockchain/carrefour-says-blockchain-tracking-boosting-sales-of-some-products-idUSKCN1T42A5. (retrieved on 31 July 2020).

Neumeier, A., Wolf, T., and Oesterle, S. 2017. “The Manifold Fruits of Digitalization - Determining the Literal Value Behind.” *13th International Conference on Wirtschaftsinformatik* 4801:484–98.

Neville, S. 2013. “Horsemeat lasagne scandal leaves Findus reputation in tatters.” *The Guardian.* Available at: https://www.theguardian.com/business/2013/feb/08/horsemeat-lasagne-scandal-findus-reputation (retrieved on 24 September 2020).

OECD and KPMG 2019. “Is There a Role for Blockchain in Responsible Supply Chains?” Available at: https://mneguidelines.oecd.org/Is-there-a-role-for-blockchain-in-responsible-supply-chains.pdf (retrieved on 28 June 2020).

OECD 2005. “Investments in weak governance zones.” Available at: https://www.oecd.org/corporate/mne/35397593.pdf (retrieved on 15 October 2020).

Oclarino, R. 2020. “Blockchain’s Technology of Trust.” ISO. Available at: https://www.iso.org/news/isofocus_142-5.html (retrieved on 27 September 2020).

Parviainen, P., Tihinen, M., Kääriäinen, J., and Teppola, S. 2017. “Tackling the Digitalization Challenge: How to Benefit from Digitalization in Practice.” *International Journal of Information Systems and Project Management* 5(1):63–77.

Patton, M. Q. 1990. *Qualitative evaluation and research methods*. Beverly Hills: Sage.

Pearson, S., May, D., Leontidis, G., Swainson, M., Brewer, S., Bidaut, L., Frey, J. G., Parr, G., Maull, R., and Zisman, A. 2019. “Are Distributed Ledger Technologies the Panacea for Food Traceability?” *Global Food Security* 20(February):145–49.

Pemberton Levy, H. 2019. “The Reality of Blockchain.” *Gartner*. Available at: https://www.gartner.com/smarterwithgartner/the-reality-of-blockchain/ (retrieved on 20 September 2020).

Pfaffenbach, C. 2011. Methoden qualitativer Feldforschung in der Geographie. In: Gebhardt, Hans, Glaser, Rüdiger, Radtke, Ulirch und Reuber, Paul (Hrsg.): Geographie – Physische Geographie und Humangeographie. 2. Auflage. Heidelberg: Spektrum Akademischer Verlag.

Provenance 2015. “Blockchain: the solution for transparency in product supply chains”. Available at: https://www.provenance.org/whitepaper (retrieved on 1 September 2020).

Provenance 2016. “From shore to plate: tracking tuna on the blockchain”. Available at: https://www.provenance.org/tracking-tuna-on-the-blockchain#overview (retrieved on 1 September 2020).

Queiroz, M. M., Telles, R., and Bonilla, S.H. 2019. “Blockchain and Supply Chain Management Integration: A Systematic Review of the Literature.” *Supply Chain Management* 25(2):241–54.

Radocchia, S. 2019. “Know What's GMO: Why Blockchain Will Build Faith In Food Labels.” *Good Audience*. Available at: https://blog.goodaudience.com/know-whats-gmo-why-blockchain-will-build-faith-in-food-labels-9b25f3a4f7ba (retrieved on 14 July 2020).

Reuber, P. and Gebhardt, H. 2011. Wissenschaftliches Arbeiten in der Geographie. In: Gebhardt, H., Glaser, R., Radtke, U. und Reuber, P. (Hrsg.): Geographie – Physische Geographie und Humangeographie. 2. Auflage. Heidelberg: Spektrum Akademischer Verlag, 89-101.

Ricadela, A. 2019. “Blockchain Records Are Forever In Opaque Diamond Market.” *Forbes*. Available at: https://www.forbes.com/sites/oracle/2019/07/12/blockchain-records-are-forever-in-opaque-diamond-market/#6d321024270b (retrieved on 13 July 2020).

Right Origin. N.d. Available at: https://www.rightorigins.com/ (retrieved on 14 September 2020).

Rifkin, J. 2011. *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World*. Vol. 11.

Ringenson, T., Höjer, M., Kramers, A., and Viggedal, A. 2018. “Digitalization and Environmental Aims in Municipalities.” *Sustainability (Switzerland)* 10(4):1–16.

Risius, M. and Spohrer, K. 2017. “A Blockchain Research Framework: What We (Don’t) Know, Where We Go from Here, and How We Will Get There.” *Business and Information Systems Engineering* 59(6):385–409.

Romano, D. and Schmid, G. 2017. “Beyond Bitcoin: A Critical Look at Blockchain-Based Systems.” *Cryptography* 1(2):15.

Rosencrance. 2017. “Blockchain Technology Will Help The World Go Green.” *Nasdaq*. Available at: https://www.nasdaq.com/articles/blockchain-technology-will-help-the-world-go-green-2017-05-09 (retrieved on 18 September 2020).

Saberi, S., Kouhizadeh, M., Sarkis, J., and Shen, L. 2019. “Blockchain Technology and Its Relationships to Sustainable Supply Chain Management.” *International Journal of Production Research* 57(7):2117–35.

Sankar, L. S., Sindhu, M., and Sethumadhavan, M. 2017. “Survey of Consensus Protocols on Blockchain Applications.” *2017 4th International Conference on Advanced Computing and Communication Systems, ICACCS 2017* 7–11.

Schlegel, M., Zavolokina, L. and Schwabe, G. 2018. “Blockchain Technologies from the Consumers’ Perspective: What Is There and Why Should Who Care?” in *Proceedings of the 51st Hawaii International Conference on System Sciences*.

Schneider, P. 2018. “Managerial Challenges of Industry 4.0: An Empirically Backed Research Agenda for a Nascent Field.” *Review of Managerial Science* 12(3):803–48.

Seemann, M. 2012. “Das müssen Sie über LTE wissen”. *PC Magazin*. Available at: https://www.pc-magazin.de/ratgeber/das-muessen-sie-ueber-lte-wissen-1277030.html (retrieved on 16 Novemeber 2020).

Smith, R. 2018. “What is the Environmental Impact of Bitcoin Mining.” *Coincentral*. Available at: https://coincentral.com/what-is-the-environmental-impact-of-bitcoin-mining/ (retrieved on 3 October 2020).

Stiller, B., Rafati, S., Grossenbacher, S., Dordevic, D., Hurschler, M., and Nabi, A. 2019. “Application of Blockchain Technology in the Swiss Food Value Chain (Foodchains).”

Stolterman, E. and Croons Fors, A. 2004. “Information Technology and the Good Life.” *Information Systems Research Relevant Theory And Informed Practice,* 687-692.

Suprunov, P. 2018. “5 Hyperledger Projects In Depth”. *Medium.* Available at: https://medium.com/practical-blockchain/5-hyperledger-projects-in-depth-3d14c41f902b (retrieved on 22 July 2020).

Tan, K. C. 2001. “A Framework of Supply Chain Management Literature.” *European Journal of Purchasing and Supply Management* 7(1):39–48.

Tayeb, S. and Lago, F. 2018. “Blockchain Technology : Between High Hopes and Challenging Implications.” *The Mena Business Law Review* 1(2):1–27.

TE-FOOD n.d.. “Farm-to-table food traceability on blockchain.” Available at: https://www.te-food.com/index.html (retrieved on 30 July 2020).

TE-FOOD 2019. “Die Migros, die grösste Supermarktkette der Schweiz, führt ein Blockchain basiertes Lebensmittel-Verfolungssystem ein.” *Medium*. Available at: https://medium.com/te-food/die-migros-die-grpercentC3percentB6percentC3percent9Fte-supermarktkette-der-schweiz-fpercentC3percentBChrt-ein-blockchain-basiertes-20cabac013eb (retrieved on 31 July 2020).

Thomas, D. J. and Griffin, P. M. 1996. "Coordinated Supply Chain Management." *European Journal of Operational Research* 94(1):1–15.

Thomasson, E. 2019. "Carrefour says blockchain tracking boosting sales of some products." *Reuters*. Available at: https://www.reuters.com/article/us-carrefour-blockchain/carrefour-says-blockchain-tracking-boosting-sales-of-some-products-idUSKCN1T42A5 (retrieved on 31 July 2020).

Thun, S., Kamsvåg, P. F., Kløve, B., Seim, E. A., and Torvatn, H. Y. 2019. "Industry 4.0: Whose Revolution? The Digitalization of Manufacturing Work Processes." *Nordic Journal of Working Life Studies* 9(4):39–57.

Tian, F. 2016. "An agri-food supply chain traceability system for China based on RFID & blockchain technology, " *2016 13th International Conference on Service Systems and Service Management (ICSSSM)*, 1-6.

Tian, F. 2018. "An information System for Food Safety Monitoring in Supply Chains based on HACCP, Blockchain and Internet of Things."

Treiblmaier, H. 2018. "The Impact of the Blockchain on the Supply Chain: A Theory-Based Research Framework and a Call for Action." *Supply Chain Management* 23(6).

Trienekens, J. H., Wognum, P. M., Beulens, A. J. M., and Van Der Vorst, J. G. A. J. 2012. "Transparency in Complex Dynamic Food Supply Chains." *Advanced Engineering Informatics* 26(1):55–65.

UNEP 2009. "The role of supply chains in addressing the global seafood crisis." 1–80.

Van Der Meulen, R. (2018). "Blockchain for Supply Chain Requires These 5 Lessons." Available at: https://www.gartner.com/smarterwithgartner/blockchain-for-supply-chain-requires-these-5-lessons/ (retrieved on 7 February 2020).

Van Der Vorst, J. G. A. J. 2006. "Product Traceability in Food-Supply Chains." *Accreditation and Quality Assurance* 11(1–2):33–37.

Visser, C. and Hanich, Q. 2018. "How blockchain is strengthening tuna traceability to combat illegal fishing." *The Conversation*. Available at: https://theconversation.com/how-blockchain-is-strengthening-tuna-traceability-to-combat-illegal-fishing-89965 (retrieved on 15 November 2020).

Wang, Y., Han, J. H., and Beynon-Davies, P. 2019. "Understanding Blockchain Technology for Future Supply Chains: A Systematic Literature Review and Research Agenda." *Supply Chain Management* 24(1):62–84.

Wang, Y., Singgih, M., Wang, J., and Rit, M. 2019. "Making Sense of Blockchain Technology: How Will It Transform Supply Chains?" *International Journal of Production Economics* 211(February):221–36.

White, C. 2018. "PNA partners with Gustav Gerig on blockchain traceability, expands tracking of FADs." Available at: https://www.seafoodsource.com/news/supply-trade/pna-partners-with-gustav-gerig-on-blockchain-traceability-expands-tracking-of-fads (retrieved on 14 November 2019).

Whiting, K. 2020. “Blockchain could police the fishing industry – here’s how.” Available at: https://www.weforum.org/agenda/2020/02/blockchain-tuna-sustainability-fisheries-food-security/ (retrieved on 10 March 2020).

WHO 2015. “WHO's first ever global estimates of foodborne diseases find children under 5 account for almost one third of deaths.” *World Health Organization*. Available at: https://www.who.int/news/item/03-12-2015-who-s-first-ever-global-estimates-of-foodborne-diseases-find-children-under-5-account-for-almost-one-third-of-deaths (retrieved on 31 August 2020).

Wognum, P. M., Bremmers, H., Trienekens, J. H., Van Der Vorst, J. G. A. J., and Bloemhof, J. M. 2011. “Systems for Sustainability and Transparency of Food Supply Chains - Current Status and Challenges.” *Advanced Engineering Informatics* 25(1):65–76.

Word Economic Forum 2018. “Building Block(Chain)s for a Better Planet - Fourth Industrial Revolution for the Earth Series.” *Weforum.Org* (September).

Wust, K. and Gervais, A. 2018. “Do You Need a Blockchain?” *Proceedings - 2018 Crypto Valley Conference on Blockchain Technology, CVCBT 2018* (i):45–54.

Yiannas, F. 2018. “A New Era of Food Transparency Powered by Blockchain.” *Innovations: Technology, Governance, Globalization*, *12*(1-2), 46-56.

Yoo, M. and Won, Y. 2018. “A Study on the Transparent Price Tracing System in Supply Chain Management Based on Blockchain.” *Sustainability (Switzerland)* 10(11).

Zheng, Z., Xie, S., Dai, H., Chen, X., and Wang, H. 2017a. “Blockchain Challenges and Opportunities : A Survey Shaoan Xie Hong-Ning Dai Huaimin Wang.” *International Journal of Web and Grid Services* 14(4): 352–75.

Zheng, Z., Xie, S., Dai, H., Chen, X. and Wang, H. 2017b. “An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends.” *Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017* (October):557–64.

9 Appendix

Appendix 1: Example of interview guidelines (blockchain provider)

Greeting:

- Information
  - Research aims of my master thesis
  - Thanking
  - Duration of the Interviews: ca. 60 minutes
- Explanation: Transliteration, recording is for personal use only, confidential use of data
- Agreement to record interview
- Information about anonymity
- Ask questions if something is not clear

Introduction:

- Can you briefly introduce yourself and your work?
- What kind of blockchains do you offer?
  - Are there smart contracts in your blockchains?
- Can you explain me a real example of a product supported by your company where the blockchain technology is applied?
  - And how would you assess its effectiveness?

Private blockchains:

- How do you assess the potential of private blockchains for a more efficient supply chain management within the food industry?
- How can a private blockchain improve the supply chain management?
- To what extent is a supply chain management with a blockchain more efficient than an existing SCM without a blockchain?
- How do private blockchains and smart contracts affect existing business relationships?
  - What does it mean for intermediaries?

Public blockchains:

- How do you assess the potential of public blockchains for tracing food products along the supply chain of a retailer?
- What are the reasons for retailers to integrate blockchain technology in their supply chain management?
- Who are the main beneficiaries when a blockchain is applied?
- For what kind of products does it make sense to deploy a public blockchain in particular?
  - What information should the blockchain contain in this case?
- Are there any other projects with an integrated blockchain you would like to tell me about?
- What companies in the food industry may take advantage of the blockchain?
  - Rather big ones or small-sized ones?
  - And what does it mean for small-sized companies?
- How high do you think is the demand by consumers to trace food products from the supermarket to its origin?

- To what extent can a public blockchain technology enhance trust and improve reputation of a retailer?

Challenges and more in-depth information about blockchains:

- Why aren't blockchains more commonly applied in the food sector yet?
- What impact does the blockchain technology have on food-labels?
    - Are there plans to cooperate with food-labels?
- To what extent does the blockchain technology provide an efficient mechanism for governing social and environmental sustainability issues along supply chains?
    - To what extent can blockchains prevent corruption and fraud?
    - To what extent can blockchain prevent labor exploitation?
    - How can the blockchain technology prevent food waste along supply chains?
- Where do you see remaining challenges when blockchains are applied?
- How do you think can the problem of the *first mile* be overcome where an efficient control mechanism verifies the raw data entering the blockchain?
- How can be safeguarded that no fish was caught in illegal waters as vessels can legally travel through them?
- To what extent are sensors within the blockchain tamper-proof?
    - How could this problem be overcome in the future?
- Can you tell me how energy-intensive public and private blockchains are?
- Can you explain me how high the costs for implementing a blockchain for a supply chain are?
    - To what extent do the savings through implementing a blockchain cover its costs of operation in the SCM?
- To what extent is there a competition among retailers to implement blockchain technology in their supply chains to keep up with the ongoing digitalization?
    - To what extent can a retailer stand out from its competitors by implementing a blockchain within their SCM?

Outlook:

- What does the future look like regarding blockchains in supply chains?
- To what extend will the blockchain technology disrupt the existing food supply chain management?
    - What does it mean for intermediaries?
- How do you expect will the number of projects with integrated blockchains in the food industry change?
- If you estimate the potential of blockchains in the food industry as high, when do you think will blockchains be a standard in the food industry?
- How high is the probability that there will be one uniform blockchain within supply chains for all the retailers one day?
- There are voices that are critical about the potential of the blockchain technology. To what extent do you agree with this opinion?

Closure:

- Do you have any further comments or experiences about this topic you would like to tell me?
- Do you have any further persons you can recommend me for an interview?
- Thank you very much for your time

Appendix 2: Coding tree of the qualitative content analysis

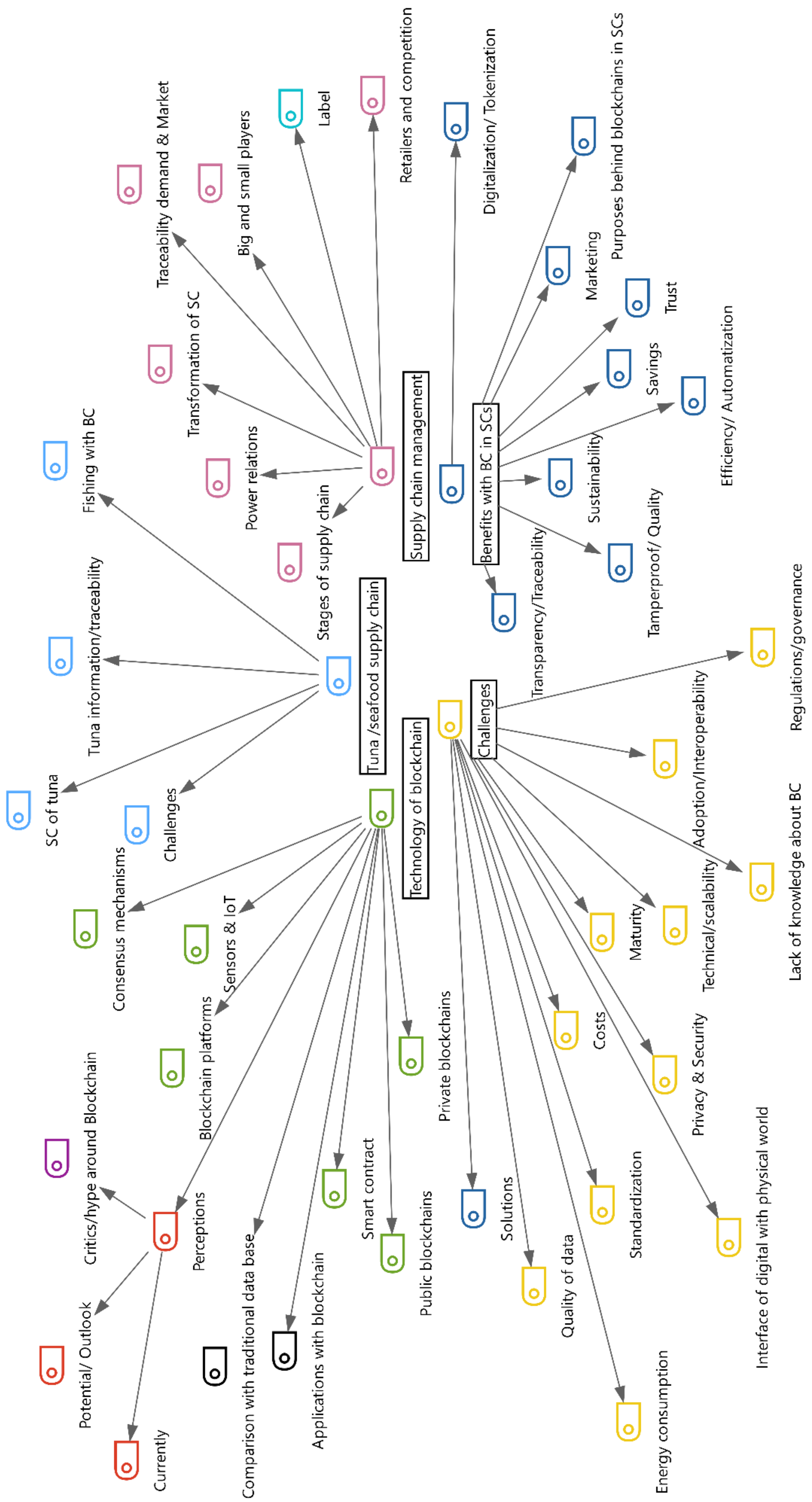

Figure 10 Coding tree of the qualitative content analysis. Own illustration, created with MAXQDA

Personal declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Zurich, 30.11.2020

Mark Egloff