IIIEE Thesis 2018:34

Sustainability Certification Goes Blockchain

A Case Study on the Added Value and Impact of Blockchain on Third-party Sustainability Certification

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Thesis for the fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, September 2018

THE INTERNATIONAL INSTITUTE FOR
INDUSTRIAL ENVIRONMENTAL ECONOMICS

Published in 2018 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
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ISSN 1401-9191

Acknowledgements

This four-month thesis project was exciting, challenging, and even frustrating at times. I would like to thank everyone who helped me to make it a success.

Valerie, I cannot thank you enough for your incredible patience, your tireless support, and the strength that you have given me.

Thank you to Håkan Rodhe who connected me to the IIIEE's brilliant alumni network. He introduced me to Anna Broekman of HS Certifiering who acted as external supervisor to this thesis. Anna, you and HS Certifiering deserve my special thanks for inspiring me to take on this project. Your feedback and introductions to stakeholders across Sweden were invaluable. You encouraged me to push myself further and provided me with exciting opportunities to share and discuss my work with countless members of the Swedish food industry. Thank you!

Special thanks also go to Carolina Sachs at Axfoundation for her confidence and for inviting me to present my preliminary findings at the Livsmedelsdagarna 2018 conference in Tylösand.

My admiration and deepest gratitude go to Matthias Lehner who acted as academic supervisor for this thesis. Your guidance was essential, and I never had to wait for your constructive feedback, not even right after the birth of your daughter Holly.

A big thank you also goes to Alex, David and Ibrahim who acted as peer reviewers and helped to significantly improve my work.

I would also like to thank all interviewees who accepted to participate and provided their vital input to this study.

Finally, I wish to thank everyone at the IIIEE for making the institute the inspiring place it is.

Abstract

Food production accounts for some of the most significant social and environmental impacts at global scale. Reliable information on who produced a product where and under what conditions is a critical enabler for meaningful action on some of the most pressing challenges. Third party certification and labelling remain widely used tools to identify sustainably produced commodities. Fragmented auditing approaches and fraudulent supply chain actors risk undermining effectiveness and trust in certification. More efficient sharing of trustworthy information is a precondition to drive positive impact and strengthen confidence in certification and the global food system. Blockchain is a distributed electronic ledger technology that has been proposed as a potential solution by creating fully traceable, transparent and trusted supply chains through immutable record keeping. Combining blockchain technology and sustainability certification might provide stakeholders with a powerful instrument to step up transparency and sustainability in food supply chains. This thesis uses an exploratory case study approach to further define the field of research on blockchain applications for supply chain management and certification, and to show how key actors and processes might be affected by the introduction of blockchain technology. Insights from 20 expert interviews and a review of various use cases and pilot projects indicate that blockchain technology has the potential to improve the effectiveness of sustainability certification and strengthen trust in related claims. Key stakeholders, such as certification bodies, will need to adapt to a changing landscape as digitalisation further progresses in the food sector.

Keywords: third party sustainability certification, blockchain, traceability, global value chains, supply chain management

Executive Summary

This thesis explores the impacts of blockchain technology on third party sustainability certification for food commodities.

Reliable information on who produced a product where and under what conditions is a critical enabler for meaningful solutions to global environmental and social challenges. Third party certification and labelling remain widely used tools to identify sustainably produced commodities. They have helped genuinely engaged producers to establish a market for sustainable products and invigorated retailer buying policies to drive best practices among suppliers.

However, standard implementation and information-sharing practices fuelled doubt over whether sustainability certification schemes and processes can live up to their promise. Fragmented auditing approaches and fraudulent supply chain actors risk undermining effectiveness and trust in certification. More efficient sharing of trustworthy information is a precondition to drive positive impact and strengthen confidence in a global food system ridden by crises and concern over unsustainable practices. Food production systems are still perceived as lagging behind compared to other industries when it comes to process digitalization, including supply chain information-sharing. Blockchain is a technology that has received considerable attention as a potential solution that could create fully traceable, transparent and trusted supply chains. The World Economic Forum describes it as „a decentralized electronic ledger system that creates a cryptographically secure and immutable record of any transaction of value" (2018, p. 5).

Combining blockchain technology and sustainability certification might provide stakeholders with a powerful instrument to step up transparency and sustainability in food supply chains. This thesis explores the possible impacts of blockchain technology on sustainability certification and collates first experiences. It contributes to a better understanding of whether and how blockchain technology can help create more sustainable food value chains. Industry, NGOs, and various UN agencies have begun to scrutinise blockchain as a decentralized immutable source of provenance information that is expected to provide food supply chains with new powerful tools. But just as the technology itself, practical experiences and related academic work are nascent. This thesis aims to

(1) Provide a contribution to further define the field of research on blockchain applications for supply chain management and certification.

(2) Share practical insights into how key actors and processes in sustainability certification might be affected by the introduction of blockchain technology.

It is designed as an exploratory case study that involves a near comprehensive set of actors that would be involved in a generic certified sustainable supply chain. Insights from 20 expert interviews and a review of various use cases and pilot projects provide important lessons learned for academia and practitioners working with sustainability certification. In particular certification bodies will find a useful overview of expected and experienced impacts on their operations. But also, retailers and producers can build on the provided insights to start exploring the most adequate solutions for their purposes.

Research was guided by two main questions and a subset of hypotheses. A brief summary of results and conclusions is provided after each question.

RQ(1) How is blockchain technology impacting (sustainability) certification processes?

Bearing in mind the limitations inherent to the chosen case study approach, it was shown that blockchain technology has the potential to strengthen supply chain and certification scheme integrity. Its ability to provide the backbone for powerful traceability infrastructures, enabling immediate access to relevant traceability events was confirmed. Chain of custody certification processes stand to benefit the most from an immutable digital support structure as provided by blockchain technology. Increasing overall audit efficiency and effectiveness seems also a likely outcome where blockchain applications are built to support certification processes and supply chain assurance. However, this remains to be seen as more experience is being gathered with such applications. Strengthening trust in brands and products was also seen as a key reason for companies to engage in blockchain projects. This appears to be an important lesson for certification schemes that consider different alternatives to build up digital traceability infrastructures under their labels. The censorship resistance of blockchain-secured information seems to have created a high level of trust by different market actors in systems using this technology.

RQ(2) How will blockchain technology impact the operations of certification bodies?

Certification bodies are key actors in the realm of independent third-party sustainability certification. Initial concerns that the certification industry might become obsolete could not be confirmed. Nevertheless, some drastic changes can be expected in the mid to long-term perspective. The effects on certification bodies are likely to vary massively between different value chains and are dependent on who introduces a blockchain-based application and with what purpose as these factors will affect the scope of a certification body's current and future activities.

While overall there was no clear indication for a diminished need of certification body services, there were indications that activities might shift in a blockchain scenario. This could include reducing the need for certain audit types, improving risk-oriented audit approaches, as well as new tasks in blockchain-supported systems. This in turn seems to require new skills to be able to integrate solutions with client systems and audit data collection infrastructure. The advent of blockchain technology offers also new business opportunities for certification bodies. This was shown by different actors who started launching new traceability services, including traceability systems and consumer facing labels that enable farm-to-fork provenance documentation.

Conclusions and recommendations.

Food industries are often considered to be slow in adapting new technologies and fully embracing digitalisation. Blockchain, along with many other relevant technologies, such as digital sensors, and artificial intelligence making sense of big data streams, may help propel the sector to a modern era. The possibility to share tamper-proof records along supply chains is a significant benefit of blockchain technology, but several challenges remain to be solved.

- Ensuring first step data quality to avoid the old 'garbage in, garbage out' problem.
- Making the technology easily accessible and ensuring it does not result in excluding smallholders from the market.
- Preventing misuse that could give false credibility to claims based on incorrect information.

The results from this work indicate that it is not blockchain alone that will do the job of solving the initially mentioned problems. Many of the advantages associated with blockchain technology, such as traceability and trackability of products, are not solely related to the technology as such but come with increased digitalisation of supply chains. While being a powerful instrument, blockchain technology should not be considered the silver bullet to all integrity issues within food supply chains. Stakeholders along food supply chain should continue to experiment and evaluate the benefits that blockchain can bring to their business, including reducing their environmental footprint. This thesis provides an overview of expected impact areas and issues to be kept in mind when evaluating the impact areas and benefits along certified supply chains.

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Abbreviations

AB	Accreditation Body
ASC	Aquaculture Stewardship Council
BAP	Best Aquaculture Practices Certification
BCT	Blockchain Technology
CB	Certification Body
DLT	Distributed Ledger Technology
FAO	Food and Agriculture Organization of the United Nations
GAA	Global Aquaculture Alliance
GMO	Genetically Modified Organism
IoT	Internet of Things
ISO	International Organization for Standardization
MSC	Marine Stewardship Council
RSB	Roundtable for Sustainable Biomass
RSPO	Roundtable for Sustainable Palm Oil
UN	United Nations
WWF	World Wildlife Fund for Nature

1 Introduction

Global food production doubled over the past 50 years, supporting a trend of decreasing hunger and malnutrition[1] (UNEP, 2016). Growth in production and globalisation of food supply chains also came at the cost of severe environmental and social impacts. Over 37% of ice and desert-free land is now used for food crops (Poore & Nemecek, 2018, p. 2) and industrial fishing activities cover over 55% of all ocean area (Kroodsma et al., 2018). Food production and processing activities account for nearly a third of anthropogenic greenhouse gas emissions (Poore & Nemecek, 2018, p. 2) and 60% of all biodiversity losses (UNEP, 2016, p. 21). Poor management of natural resources and increasing economic pressures have also contributed to human rights violations, including forced labour and trafficking (EJF, 2015).

Societal pressures and genuine concern about the aforementioned issues have resulted in various initiatives driven by NGOs, industry and governments. One popular approach, especially among retailers, was making third-party sustainability certification a mandatory sourcing requirement (Albersmeier, Schulze, Jahn, & Spiller, 2009, p. 927). The market for certified sustainable food products has since moved from niche to mainstream (Lernoud et al., 2017). In parallel, the number of certification initiatives, codes of conduct, and audit protocols shot up, with Standards Map currently listing over 180 food related entries (ITC, 2018). While surveys highlight the importance of sustainability certification in guiding consumption choices, the proliferation of labels and possibly unsubstantiated claims undermines consumer trust that labels are actually ensuring more sustainable practices (Lambin & Thorlakson, 2018, p. 6). It is not surprising that independent verification through third parties has become more important for consumers when deciding to trust in certification schemes and their labels (MSC, 2018).

While the demand for sustainably certified products is growing rapidly, supply is often not able to keep up (Duggan & Kochen, 2016, p. 30). This supply gap and the possibility to reap premiums has created incentives to slip non-compliant products into global and often difficult to monitor value chains. Fraudulent actors have repeatedly sought to exploit weaknesses in certification processes. Issues range from ignoring production standards to inflating product volumes by introducing non-certified materials into certified value chains (Freitas, 2014; Marko, Nance, & Guynn, 2011; MSC, 2014). In 2011, the Italian police arrested a criminal organisation that had supplied over 700,000 tons of fake organic vegetables to various European countries by forging documents and bribing certifiers (Spiegel Online, 2011). Fraud in the form of introducing non-allowable products into certified supply chains may be incentivised through significant premiums and a fair chance to pass unnoticed. In 2016, a Ukrainian shipment of soy beans to the US was falsely declared as USDA organic compliant, resulting in an estimated additional sales revenue of four million US dollars. About a third of the shipment was sold into the US market before authorities noticed the fraud (Whoriskey, 2017).

The level of supply chain integrity issues across certified value chains is unclear and may well be small or inexistent across many certification schemes. Still, there is no doubt that each scandal undermines buyer and consumer trust. The simple perception of potential fraud puts third-party certification at risk and may erode its legitimacy. Certification comes at an additional cost to consumers (Ponte, 2008, p. 167). That cost must be justified through added value derived for customers and consumers and requires rigorously following defined processes to

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[1] It should be noted that the 2018 report on the State of Food Security and Nutrition in the World indicates a rising number of malnourished people. While climate change is considered as one possible reason, the main cause appears to be the rise in violent conflicts (FAO, IFAD, UNICEF, WFP, & WHO, 2018).

build credibility with stakeholders (Tröster & Hiete, 2018, p. 2). However, the reality of verification procedures along certified food supply chains may not always make this an easy task. Auditors are often required to work their way through paper-based systems or electronic database silos that do not communicate beyond company borders (RSB, Provenance, & ISEAL Alliance, 2018). Supply chains consist of multiple actors and each actor's processes and management systems need to be certified for the final product to carry a label. Especially in supply chains spreading across several borders, this often involves multiple disconnected certification bodies that don't necessarily compare their findings. This makes it difficult to detect inconsistencies in product flows, creating loopholes for errors and fraud. The standards community places strong hopes in online databases to provide a remedy (Komives & Jackson, 2014, p. 10) and various tools have been proposed and tested.

Blockchain, better known for being the technology that powers cryptocurrencies like Bitcoin, has received considerable attention for its potential to create fully traceable, transparent and trusted supply chains (Abeyratne & Monfared, 2016; Francisco & Swanson, 2018; Yuva, 2017). The World Economic Forum describes it as „a decentralized electronic ledger system that creates a cryptographically secure and immutable record of any transaction of value, whether it be money, goods, property, work or votes" (World Economic Forum, 2018, p. 5). It can thus provide the backbone for systems that enable managing records as well as tracing and tracking goods along supply chains.

The technology was initially conceived to facilitate secure peer-to-peer exchange of digital property titles between anonymous trading partners in a low trust environment without having to rely on a trusted third party. The central problem in these situations is the risk of fraudulent participants spending their funds several times in the absence of a third party or mechanism to verify account balances and clear transactions accordingly (Nakamoto, 2008, p. 1). This is also referred to as 'double-spent problem'. Initially discussed in the context of electronic cash, similar problems could also occur when companies reuse proof for certified products, like invoices (NEPCON, 2017), to inflate their trade in certified products. If all events are digitally registered, blockchain technology can prevent this through cryptographic capture and storage of transactions in a time-stamped log that is shared by all network participants (Risius & Spohrer, 2017, p. 386). Such a network can include everyone with access to the internet or be restricted to actual supply chain network members. Key advantages for supply chain members include the creation of production records that are (Dapp, Balta, & Krcmar, 2017, p. 3):

(1) Transparent, as every participant can see the transaction history;
(2) Durable, as the distributed network structure eliminates single points of failure that could put the transaction history at risk;
(3) Immutable, as a powerful consensus mechanism and the append-only data structure provides protection from fraud.

Expectations in the positive impact of blockchain technology on supply chain integrity are high. Walmart and IBM made global headlines when they announced the reduction of traceback time for a pack of sliced mango from a week to just two seconds, thanks to a blockchain-based traceability application (Nash, 2018). Authors have called "blockchain technology […] a revolutionary innovation with capability to transform many existing traditional systems into more secure, distributed, transparent, collaborative systems while empowering its users." (Abeyratne & Monfared, 2016, p. 8). It has been characterized as disruptive (Saberi, Kouhizadeh, & Sarkis, 2018), possibly bringing supply chain transparency to a new level (Francisco & Swanson, 2018; Kim & Laskowski, 2016) by addressing the lack of trust, transparency and documentation (Di Ciccio et al., 2018), and potentially even playing an important role in achieving the United Nations Sustainable Development Goals (Kewell, Adams, & Parry, 2017). While expectations might be exaggerated, a Deloitte survey shows that supply chain use cases continue to be the most common non-financial application of blockchain technology development, promising an increasing number of successful applications (2018, p. 29). The Food and Agriculture Organisation of the United Nations (FAO) expects blockchain technology to improve agricultural supply chains through (1) improved traceability, (2) disintermediation, and (3) building digital identities for physical assets (Tripoli & Schmidhuber, 2018, p. vi).

Combining blockchain technology and sustainability certification might provide stakeholders with a powerful instrument to step up transparency and sustainability in food supply chains. The aim of this thesis is therefore to explore the possible impacts of blockchain technology on sustainability certification and to collate first experiences. The overarching research objective is to contribute to the understanding of whether and how blockchain technology can help create more sustainable (food) value chains.

The thesis is designed as an exploratory case study, drawing from examples across various supply chains and certification schemes as experiences with the technology are still scattered. While this is not a classical case study approach, the relatively similar functioning of certification in different value chains allows to derive relevant conclusions. Data is generated through expert and practitioner interviews as well as grey literature.

1.1 Problem definition

Expectations towards the transformational influence of non-financial blockchain applications on today's economy are significant, while much of the scholarly debate is based on thought experiments (Kshetri, 2018), pilots that did not involve the development of actual applications (RSB et al., 2018), and only very few real world-tested and rolled-out applications (Pacifical, 2018). Supply chain management is no exception to this observation and scholars' claims about the impact of blockchain technology have not yet been systematically assessed (Kshetri, 2018, p. 80). Saberi et al. (n.d., p. 18) identified a new research agenda in (sustainable) supply chain management with suppositions about the potential of blockchain to reduce opportunistic behaviour, by enabling better auditability and less intermediaries; issues that appear very relevant considering the purpose and functioning of certification schemes.

Sustainability certification schemes are supposed to create confidence in product attributes that are, for the most part, not verifiable by simply inspecting the product itself. Certification of these so-called credence attributes, like free range kept livestock, has come under attack by scholars (Froese & Proelss, 2012; Jacquet et al., 2010; Laurance et al., 2010), practitioners (Freitas, 2014; NEPCON, 2014), non-governmental organisations (BASIC, 2016; Brad et al., 2018; WWF, 2016) and media (Bünger & Pieper, 2018; Das Erste, 2018). Most of the criticism focuses on either low standards or the inconsistent application of production standards. In addition to a production standard, many certification schemes also request conformity with a chain of custody (CoC) standard. The latter mostly serves to ensure product traceability. Few studies actually address CoC issues (Düdder & Ross, 2017). This is surprising as an intact chain of custody is fundamental to the credibility of any claim and certification scheme. Traceability, the core objective of CoC certification, is expected to be significantly improved through the introduction of blockchain technology applications (Abeyratne & Monfared, 2016, p. 9; Francisco & Swanson, 2018, p. 10). Current CoC auditing is still often a paper exercise or at best based on data stored on locally accessible databases. Both might be difficult to efficiently verify but all the easier to tamper with. Albersmeier et al. (2009, p. 928) highlight the difficulty to verify the proper functioning of the required management systems by certification bodies that are brought in for a complex verification process with little time, increasing the likelihood that fraud will go unnoticed.

With blockchain on the rise, certification schemes and involved actors may experience significant changes to their modus operandi. Certification bodies will probably have to anticipate a future requiring new income streams, activities and skills. Companies handling certified products can possibly expect a shift of audit focus to risk areas. It seems that overall blockchain technology may contribute to more sustainable value chains by increasing transparency and redirecting resources where they are needed most: ensuring sustainable production practices. As highlighted, debates in academia and among practitioners are dominated by speculations, while insights into actually realised improvements are lacking. Therefore, this thesis aims to provide academic evidence for the impact of blockchain technology on sustainability certification and involved actors, in particular certification bodies. Furthermore, it is hoped that other stakeholders across certified supply chains will find the outcomes helpful to assess relevance, opportunities and impacts on their operations.

1.2 Research questions

Following from the problem definition, two research questions are raised:

RQ(1) **How is blockchain technology impacting (sustainability) certification processes**?

It is assumed that processes that are sensitive to how certification-relevant information is collected and communicated may change. In particular chain of custody assurance, auditing in general and trust in claims will be reviewed to assess the impact of blockchain technology on certification processes.

RQ(2) **How will blockchain technology impact the operations of certification bodies?**

Certification through an independent third party is currently considered best practice in sustainable supply chain assurance. However, the paradigm underlying blockchain technology postulates significantly reduced need for third party assurance. By answering RQ (2) this thesis seeks to elucidate blockchain's impacts on activities, required skills and business opportunities for certification bodes.

1.3 Limitations and scope

The limitations of this work are mostly linked to the experimental nature of practical applications and the limited availability of relevant academic work. Research on blockchain technology application in supply chain management is very young as an academic field. The rapidly increasing interest and fast-growing body of literature make it difficult to pinpoint the "state of the art" and avoid omissions. The author is not aware of any comparable study that specifically addresses the interplay of blockchain technology and sustainability certification. This might limit the validity of assumptions about certain relationships presented in the analytical framework, as they are not based on previous work that would exactly match the described case.

The practical limitations encountered are similar. Blockchain technology applications outside of finance are nascent (Kshetri, 2018, p. 80; RSB et al., 2018) and no complete case of a certified supply chain using blockchain was accessible to the author. It seems that deployment and application of the technology will differ drastically as they are likely to be influenced by company size, supply chain configuration, and innovativeness of the certification schemes involved. Large companies with streamlined supply chains may find it easier to implement the technology while those rooted in a small-scale supplier network will probably encounter more challenges. Younger certification schemes that developed in parallel to the rise of Industry 4.0[2] might find it easier to adopt than the precursors who already achieved significant market share. However, time constraints inherent to a three-month thesis did not allow to ensure that a representative set of differently sized actors within the relevant stakeholder groups was interviewed.

Methodological limitations stem from the case study design. As no single case of an entire certified supply chain being run on a blockchain application was found, an abstract case was constructed based on experiences from various supply chains and organizations. This may well limit the generalisability of findings as there is a risk that relevant in-case relationships and effects were overlooked.

1.4 Ethical Considerations

This study relied on semi-structured interviews that involved sensitive issues, such as fraud in supply chains and failures of existing assurance mechanisms. Interviews were therefore only recorded after oral consent. Direct quotations or any contents that could be easily linked to an organization or person were shared for clearance with a ten-day approval period.

Interviews were conducted mostly online with some in-person exceptions (see Appendix I). Interviewees were provided with a description of the project background and objectives as well as how the provided information would be used. They were also made aware of their opportunities to flag any statements that they would not like to see as part of the final publication.

The semi-structured interviews were based on a common questionnaire that was adapted depending on the interviewees' expertise. Questionnaires were provided in advance to allow for preparation and clarification of any questions. When conducting the interviews, great care was taken to avoid leading interviewees to particular responses. However, to clarify certain questions or provoke a reaction, the author confronted the interviewees with hypotheses as reflected in the analytical framework.

1.5 Audience

Research on sustainability certification schemes has predominantly focused on value chain governance (Bernstein & Cashore, 2007; Bush, Oosterveer, Bailey, & Mol, 2015; Gulbrandsen, 2010; Nesadurai, 2018; Ponte & Gibbon, 2005), institutional architecture(Roberts, 2013), as well as rigor of standards and their impact (Agnew et al., 2013; Froese & Proelss, 2012; Gutiérrez et al., 2012; Jacquet et al., 2010; Ruysschaert & Salles, 2014). A diverse set of IT technologies with potentially disruptive impact on supply chains has been emerging over the past decade (Korpela, Hallikas, & Dahlberg, 2017; Wu et al., 2017). Astonishingly little attention has been devoted to the impact of information technology on sustainability

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[2] Hofman & Rüsch (2017, p. 25) define industry 4.0 as an industry characterised by (1) flexible connection of product and service through network applicatiosn; (2) digital connectivty enabling automated and self-optimising production; and (3) decentralised controlling of value networks with autonomous decision making by system elements. The World Economic Forum emphasises how the combination of technologies like artificial intelligence, internet of things and others "increasingly merge the digital, physical and biological realms, [...] increas[ing] the speed, intelligence and efficiency of business and societal processes"(World Economic Forum, 2017, p. 7)

certification and integrity of certified supply chains in general. This thesis aims to contribute to this sparsely researched area in order to provide insights for:

Academia – This work analyses expected and experienced impacts of blockchain technology on sustainability certification as a key tool in sustainable value chain governance. It is hoped that this will advance the scholarly debate on driving improvement in certification and help to highlight new areas for research.

Certification bodies – Certification bodies are the group that will probably be most impacted by blockchain technology introduction into certification processes. This work presents selected findings that illustrate how their required skillset, scope of activities and business opportunities is or will be changing.

Certification scheme owners – Blockchain-based traceability systems possibly provide certification schemes with a new instrument to consolidate market trust in their labels and claims by improving oversight of certified product flows and control over label use. In addition to further the understanding of blockchain's impacts on certification processes, this work also discusses what certification scheme owners stand to gain from using the technology for scheme integrity monitoring.

Other supply chain stakeholders – This work also addresses the impact of a technology that has been suspected to drastically improve supply chain management by enhancing traceability, transparency and overall control. It may drive significant institutional and operational changes in supply chain configuration, management and assurance processes. The author hopes to have raised questions with practical relevance that will help actors along sustainably certified supply chains to understand how BCT will impact their operations and strengthen third-party sustainability certification.

1.6 Disposition

Chapter 1 introduced the background to this research project by highlighting challenges in sustainable supply chain management, sustainability certification and how blockchain technology might be used to address some of the issues raised. It also provided the research questions that serve as the backdrop for this thesis.

Chapter 2 develops the methodological approach, including how the literature review is used to explain key concepts and to derive the analytical framework. It further explains the exploratory case study approach with a particular focus on how expert interviews with different stakeholder groups are used to construct a hypothetical supply chain case. Chapter 3 then combines and reviews different literature strands to identify the research gap in more detail, to introduce the functions and challenges of sustainability certification, and to develop a set of hypotheses how BCT may help address these. These are then condensed into the analytical framework presented in the end of that chapter.

Chapter 4 reports the main findings against the previously presented hypotheses about how BCT is likely to affect certification processes and certification bodies. Chapter 5 then goes on to present a discussion of the main findings that is structured according to the analytical framework, adding a section on implications for scheme owners.

Chapter 6 concludes this thesis by recalling the research questions and main findings. It also contributes selected research questions that should be addressed in future works to better understand detailed impacts of blockchain technology on sustainability certification.

2 Method

This section describes the applied exploratory case study approach. The methodological choice was guided by several limitations linked to the novelty of the subject at hand:

(1) BCT is still a nascent technology in both supply chain management and even more so in combination with third party sustainability certification.
(2) Cases that would reflect a full value chain, including all relevant actors, are not available or appeared inaccessible within the constraints of a master thesis.
(3) Most application cases of BCT within certified supply chains are confined to single or few actors and do not cover a full chain.

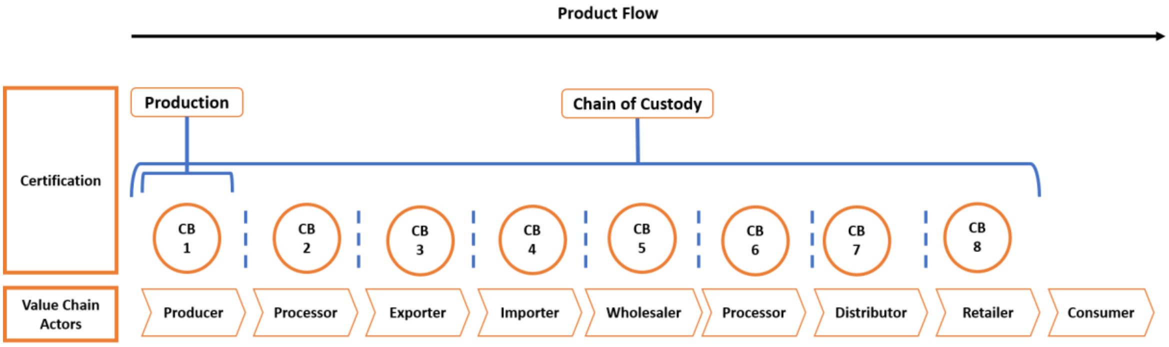
However, providing an analysis of the impact of BCT on sustainability certification and its role along value chains requires covering a set of key actors as comprehensive as possible. Third party certification schemes (across commodities) generally follow a similar structural design and actor composition and face comparable challenges. It was therefore deemed acceptable to construct a case analysis that links actors representing the different required perspectives (i.e. certification body, certification client etc.) from different schemes and supply chains.

2.1 Case oriented approach

Case-oriented approaches are often employed when the researcher focuses on very "complex, context-bound, or context-sensitive" subjects that are difficult to address otherwise (McCarthy, 2012; Yin, 2009) and may require triangulation of different methods and sources. Important objectives are to understand particular cases and causal mechanisms that are shared by relevant cases (Ragin, 1999, p. 1142).

A case-oriented approach may be useful when it focuses on a new topic with little available data and when the detail of propositions is "prioritized over breadth and boundedness" (Gerring, 2004, p. 352). Its strengths include the ability to open up new research fields through studies with a strong exploratory focus (Gerring, 2004, p. 349). According to Gerring, a case is best understood as an in-depth analysis of a single event or unit with the objective to develop explanations valid to similar cases (Gerring, 2004, p. 352). In the present study a broader perspective is chosen. Third party sustainability certification as a value chain management tool is considered a "use case" for blockchain technology. To assess the impacts on certification and the involved actors, a full value chain perspective is chosen. Figure 1 represents a simplified depiction of a food product value chain.

Figure 2-1 - Simplified food value chain and coverage of certification



Source: Own elaboration.

The abstract case construct is populated with real cases representing different segments of certified value chains. An example would be the PNA based tuna marketing company Pacifical, whose blockchain traceability application (Pacifical, 2018) covers harvesting, transport, processing and canning of their Marine Stewardship Council (MSC) certified tuna, but not the rest of the downstream part of the supply chain[3]. Other cases and actors, like certification bodies active all along the supply chain, help to come to a more complete assessment of impacts.

2.2 Exploratory approach

The exploratory case study approach is fit for new fields of scientific investigation where the required data for hypothetical formulations has not yet been generated (Streb, 2010, p. 2). Yin (Yin, 2009, p. 5) lists the development of pertinent hypotheses for further research as a strength of this approach when developing new research fields, as they may provide insights into path defining cases in data deficient situations (Streb, 2010, p. 2).

The approach seems appropriate to analyse blockchain technology implications for supply chain management and certification and was also applied by other recent studies (Folkinshteyn & Lennon, 2016). Its particular advantage is its flexibility and independence from any particular research design or data collection methodology which "suits yet unrecognized phenomena" (Streb, 2010, p. 2). The limited generalisability of findings makes this approach more fit for theory and hypothesis generation.

Case selection in exploratory studies is guided by the objective to focus on units that highlight issues in a particular research field, similar to extreme or revelatory case selection (Streb, 2010, p. 2; Yin, 2009, p. 48). Since the availability of relevant cases is fairly limited, all analysed application cases and expert views are considered to potentially offer revelatory elements that provide insights into a new research field. Different process components and actor groups are treated as subunits of the overall case according to their importance for the impact analysis of BCT adoption on sustainability certification. Subunits are the various stakeholders involved along a certified supply chain. Such an embedded design can enhance insights by enabling comparison of the application of causal mechanisms across subunits. This design choice may also help strengthen and maintain focus by adding control units that need to be analysed following the same approach (Yin, 2009, pp. 52–53).

The flexibility of the chosen approach required great care to ensure rigor while allowing new insights and hypothesis generation throughout the research process. Internal validity was strengthened by developing a robust research framework grounded in two distinct literature fields as well as triangulation of data sources (Gibbert, Ruigrok, & Wicki, 2008, p. 1466). Construct validity in case studies is achieved through the development of a clear chain of evidence, data triangulation, peer reviews, and careful explanation of the data analysis process (Gibbert et al., 2008, p. 1467). The present work was also discussed and partially reviewed several times by supervisors and peers during the writing process. Data triangulation was ensured by generating evidence through interviews with different stakeholder groups and available grey literature. External validity of the selected case may be constrained as the effects of BCT adoption might differ across value chain management tools. However, as the selected case aims to represent a group of entities, namely certification schemes, a certain level of generalisability is still achieved by building on interviews with stakeholders across different schemes. Reliability, ensuring consistent evaluation of data, is strengthened through rigorous

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[3] MSC chain of custody certification is not required for actors handling only consumer-ready tamper-proof-packaged goods (MSC, 2015).

application of the analytical framework and structured analysis of interview data (Yin, 2009, p. 33) through the qualitative content analysis software NVivo.

2.3 Data collection

Data collection followed a two-tiered approach that involved a review of academic and grey literature as well as a set of interviews with 20 experts and practitioners.

2.3.1 Literature review

The literature review follows the "integrative review" methodology as described by Whittemore & Knafl (2005) and commonly used in sustainability science for new topics (Kohtala, 2015; Mori Junior, Franks, & Ali, 2016). The aim is to create a holistic understanding of a problem, rather than to systematically review and analyse the full body of existing literature. Advantages include the possibility to draw from a greater variation of data sources, both from a theoretical and empirical perspective, which may support portraying a complex subject (Kohtala, 2015).
This flexibility is required as the topic at hand is rapidly evolving and relevant information emerge in whitepapers, news items and other non-academic sources on an ongoing basis.

Academic literature was reviewed for three topics:

(1) A current understanding of global value chain management and the role of certification, including how third-party certification works and its commonly cited challenges.
(2) The origins and key properties of blockchain technology.
(3) Blockchain technology and its relevance for food value chain management and sustainability certification.

The objectives of this review included developing key concepts, compiling main functions, attributes, (dis-)advantages of certification schemes and blockchain technology to derive the analytical framework presented in section 3.4. Assessment criteria and codes for the collected interview data are thus based on the key functions and assumed advantages of BCT for sustainability certification.

Grey literature in the form of whitepapers, use case descriptions and other non-academic sources was reviewed to:

(1) Present use cases of BCT in supply chain management and third-party sustainability certification.
(2) Identify effects on sustainability certification schemes, processes and involved actors.

2.3.2 Expert interviews

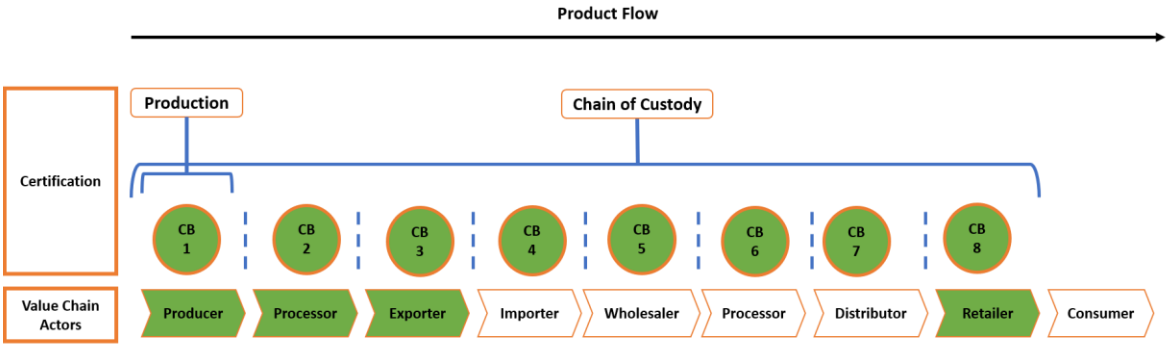
Twenty expert interviews were conducted to collate empirical evidence for impacts and expectations towards blockchain technology in sustainable value chain management. Expert interviews are a particular form of the semi-structured interview where the main interest is the institution or position interviewees represent. These are mostly staff members of an organization with a specific function and a specific professional experience and knowledge (Flick, 2009, pp. 165–166). They are commonly used "for orientation in a new field in order to give the field of study a thematic structure and to generate hypotheses" or as a near standalone method (Bogner and Menz, 2002, pp. 37 in Flick, 2009, p. 166). This methodological choice seems appropriate given the very recent emergence of research on BCT impact on supply chain management and sustainability certification.

Interviewee selection was guided by four considerations:

(1) The aim to achieve, as completely as possible, a representation of all actors involved in a hypothetical certified value chain supported by BCT as well as actors in the related certification scheme.
(2) The need to include interviewees with enough understanding of BCT and experience with its implementation in value chain contexts.
(3) The limitation that no full value chain example was known that would already have implemented a comprehensive solution involving sustainability certification and full supply chain trackability.
(4) Case study methods are often faced with the criticism of falsely rejecting the null hypothesis. Therefore, expert stakeholders with alternative technology solutions in place were also interviewed to ensure the necessary diversity for meaningful results and assess the added value BCT might bring.

Figure 2 shows (in green) which groups forming a hypothetical value chain have been interviewed. Not all groups could be included due to time constraints. However, certification bodies active along these value chains have been interviewed and provided insights pertaining to entire chains. Furthermore, representatives from all organisations making up a certification scheme (see Figure 3-1) and blockchain as well as supply chain experts engaged in blockchain projects were interviewed. A full list of interviewees can be found in Appendix A.

Figure 2-2 - Value chain stakeholders interviewed for this study



Source: Own elaboration

2.3.3 Conducting interviews

Interviewees were identified through contacts provided by HS Certifiering, the author's professional network and interviewees suggested by other interviewees. Further, prominent BCT projects from the food industry were contacted for interview requests.The initial interview guide was developed based on the topics and hypotheses contained in the analytical framework and was refined after feedback from two supervisors. Certain hypotheses were covered by follow-up questions to avoid leading interviewees to responses that would simply confirm the suppositions underlying the framework. In line with the exploratory approach, the guide for the semi-structured interviews was adapted based on the knowledge generated through previous interviews and was also slightly adapted to the parties interviewed. A consolidated version of the guide can be found in Appendix B.

2.4 Data Analysis

A three-step analytical framework (see section 3.4) covering key roles of certification and certification schemes was developed based on the literature review. These roles were contrasted with major challenges and criticisms as identified from literature and finally opposed to hypotheses how BCT will help to address these challenges. Obviously, not all functions of a certification scheme are covered within the framework. The focus is on those areas where BCT is expected to result in significant impacts. The framework guided the analysis of the interviews and the development of the initial coding.

Interviews were transcribed in full or notes. Where interviewees agreed the automated transcription service temi.com was used. These transcripts were coded using the NVivo software, version 12. A three-step process was applied for coding:

(1) In line with the deductive approach of this thesis, an initial coding structure (see Annex C) was developed based on the analytical framework. This structure was translated into nodes in NVivo.
(2) Prior to coding, all transcripts were read carefully to gain an overall impression of how well the analytical framework and nodes fit the actual interview content.
(3) A second reading, including coding, resulted in the enriched hierarchical coding structure presented in Annex D. "Enriched" refers to new nodes and sub nodes that were added for relevant topics identified across interviews but not yet covered by the analytical framework. This also helped increase the granularity of the presentation of results.

3 Literature review and analysis

The literature review is structured along three sub-sections that feed into the analytical framework in section 3.4.

Sub-section 3.1 presents a selective review of sustainability certification focusing on:

(1) Key concepts of third-party certification, involved processes and actors;
(2) An overview of the core functions certification schemes with a focus on traceability;
(3) Common criticisms towards and challenges encountered in certification processes.

Sub-section 3.2 introduces key concepts of blockchain technology (BCT).

Sub-section 3.3 provides a structured review of the fast-growing research body on the application of blockchain technology in supply chain management, assuming that sustainability certification is a key instrument in sustainable food commodity supply chain management. As literature on BCT application in sustainability certification is quasi non-existent, relevant supply chain management literature is used to support hypothesis development for the analytical framework. Sub-section 3.3 provides an overview of:

(1) Drivers, barriers and expected benefits of BCT for sustainable supply chain management;
(2) Potential consequences for existing supply chain assurance infrastructure;
(3) Use cases of BCT in sustainable supply chain management.

Sub-section 3.4 introduces the analytical framework against which the collected data will be assessed.

3.1 Certification and sustainable value chain management

Sustainability certification is extensively discussed in conservation studies (Laurance et al., 2010; Ruysschaert & Salles, 2014), and in global value chain governance literature (Gereffi, Humphrey, Kaplinsky, & Sturgeon, 2001; Gibbon, Bair, & Ponte, 2008; Lund-Thomsen & Lindgreen, 2014; Nadvi, 2008; Ponte & Gibbon, 2005). Value chain and supply chain management focus on the same practical phenomenon: the flow of materials, goods and services along a chain of actors. In addition to the forward focus of the term, "supply chain" involves the relative value of all operations that are necessary to move a product or service from production to consumption and disposal (Gereffi et al., 2001). It reveals a more complex understanding of the value creation process through supply chains by emphasizing complexity and as well as the capabilities of the various participants to make use of codification information (Bush et al., 2015, p. 10; Gibbon et al., 2008, pp. 317–318). In this context, certification schemes are one form of codifying supply chain information.

Certification schemes act as bidirectional instrument by transporting information about production processes and helping to steer those processes through commonly agreed standards. Hence, they play an important role in global value chain governance. Ponte and Gibbon (2005, p. 3) define governance as "the process of organizing activities with the purpose of achieving a certain functional division of labour along the chain, resulting in specific allocations of resources and distributions of gains." It includes setting rules for chain membership and distributing value-adding activities that the lead companies involved do not want to carry out themselves.

According to various authors, sustainability certification also helps firms to create value beyond trust in a product' credence attributes by:

- Reducing risk and strengthening supply chain control through a commonly agreed set of requirements and independent verification (Carroll & Shabana, 2010, pp. 97–100);
- Lowering transaction costs induced by supplier identification, contract negotiation, verification and enforcement (Meuwissen, Velthuis, Hogeveen, & Huirne, 2003, p. 57);
- Enhancing access to insurance and finance (Meuwissen et al., 2003, p. 57) as funds include sustainability certification in risk assessment and investment criteria (Norges Bank, 2017);
- Supporting in the fulfilment of legally binding due diligence and traceability requirements (Gavrilut, Halalisan, Giurca, & Sotirov, 2015; Meuwissen et al., 2003, p. 57);
- Positively impacting trade (Meuwissen et al., 2003, p. 57) through improved market access (Berry & Weaver, 2018; Duggan & Kochen, 2016, p. 30);
- Providing an enhanced 'license to produce' and sometimes even price premiums (Meuwissen et al., 2003, p. 57).

3.1.1 The emergence of certification

The first examples of sustainability-oriented certification date back to the organic movement in the first half of the 20th century (Komives & Jackson, 2014, p. 6). Later, NGO-led campaigns on unacceptable social and environmental conditions across global value chains made Western retailers react by establishing a "compliance-based paradigm" with certification at its core (Lund-Thomsen & Lindgreen, 2014, p. 13).

The increasingly transboundary production and evident inability (Cashore, 2002, p. 509; Gulbrandsen, 2010, p. 29; Komives & Jackson, 2014, p. 6) or unwillingness of national governments to effectively regulate and enforce sustainable resource use and workers' rights (Nesadurai, 2018, p. 205) led to the rise of private governance approaches (Bush et al., 2015, p. 8). Frustration with unsuccessful intergovernmental attempts, such as the failed forest convention at the 1993 Rio Earth summit, resulted in the creation of certification schemes like the Forest Stewardship Council (Cashore, 2002, p. 507), a model that has since been exported to food commodity value chains (Ponte, 2014, p. 263; Tallontire, Opondo, Nelson, & Martin, 2011, p. 428).

The popularity of third party certification schemes follows from the realisation that even the largest players are hardly influential enough (von Geibler, 2013, p. 39) to drive sustainability across the often fragmented agri-food sub-sectors (The Press Association, 2017). In addition to bringing together various stakeholder interests in standard-setting and scheme governance, the reliance on independent third parties was perceived sufficient to providing the required objectivity for credible assurance of more sustainable practices (Hatanaka, Bain, & Busch, 2005, p. 358).

3.1.2 The value of certification

The added value of sustainable food commodities is based on differences in production processes, which are usually not verifiable for customers and consumers by examining the physical good itself. The value of these so-called credence goods relies on trust in the accuracy of information provided with that good (Albersmeier et al., 2009, p. 928; Ponte & Gibbon, 2005, p. 2). Certification schemes and their labels thus play a crucial role in assuring and communicating this added value. Trust in a certification scheme's claims and labels is a crucial precondition to ensure trust in the credence attributes of a product.

Customer and consumer trust in the truth of a sustainability claim are derived from credible assurance that a product was indeed produced per a defined set of criteria through an independent assessment (Parkes et al., 2010, p. 352). This in turn rests on several structural and procedural aspects that will be described in this chapter.

3.1.3 Concepts, components and actors in third party certification

Authors usually differentiate between three main types of auditing that range from self-inspections to independent assessment and certification (see Table 3-1). In addition, some authors mention various other certification-like approaches with some sign of approval granted by government, NGOs or private sector auditors (Nadvi & Wältring, 2004, p. 9).

Table 3-1 - Verification or certification differentiated by auditing party

Type of system	**Description**	**Examples**
First party	Self-inspection resulting in a self-declared statement of conformity with a standard or set of self-defined requirements. It may involve a third party, especially for when controlling sub-units of the client company.	Companies declaring compliance with the ISO 9001 for quality management systems.
Second party	Inspection of party A by party B where both parties are involved in a transactional relationship, like buyers conducting an audit at supplier facility. May involve an accredited auditing company but usually does not result in certification.	Buyers auditing suppliers against certain control points included in for example working conditions, food safety and quality management standards.
Third party	Compliance Verification of a supply chain actor against a defined set of requirements usually by an accredited third-party auditing company (certification body), often resulting in a certificate of conformity.	Certification against e.g.: ISO 14001; EU Organic; Marine Stewardship Council.

Source: Own elaboration based on Gulbrandsen (2010, p. 38)

What distinguishes third party certification (TPC) from the other systems is the independence of the certifying organization from other participants involved in the supply chain or the certification scheme itself (Hatanaka et al., 2005, p. 355). This independent and impartial verification and certification is a crucial building block for a certification scheme's credibility. It rests on an interplay of various independently operating actors and processes that will be introduced in this section. While this section will not provide a full overview of all rules, organizational structures, and processes of TPCs, it aims to (1) highlight key features to derive the main functions and (2) to then introduce perceived weaknesses. For a more comprehensive understanding of what is viewed as a credible and robust certification scheme, various benchmarks such as the Global Sustainable Seafood Initiative's Global Benchmark Tool (GSSI, 2015, pp. 16–17) or the Global Food Safety Initiative's Guidance Document (GFSI, 2017) should be consulted.

Per Komives & Jackson (2014, p. 5) and Tröster & Hiete (2018, p. 2), six key structural components can be identified that represent the building blocks to a certification scheme's credibility. They are summarized in Table 3-2.

Table 3-2 - Key components of a certification scheme

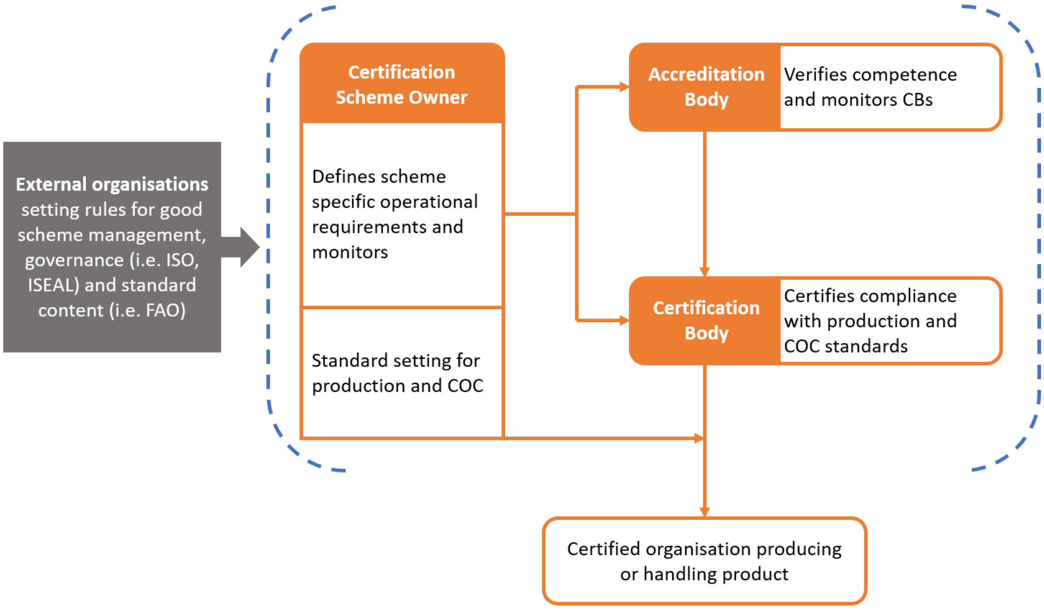
(1) Governance and standard setting process	Scheme governance and standard setting procedures define how standards are being developed, how and which stakeholders may participate and how decisions are being made by the scheme owner.
(2) Standard	A document or set of documents specifying the criteria against which a farm, fishery, production facility, or any other operation to which the standard is applicable, is assessed
(3) Assurance system	A set of actors (i.e. scheme owner, accreditation body, certification body) and processes governing their interaction that is put in place to ensure that independent certification of an operation is conducted by a competent certification body that was assessed for its competence by an accreditation body
(4) Label or claim	In most cases certified producers wish to use a certification scheme's label and/or claim on their products to differentiate themselves in the consumer facing market. Label usage is bound to conformance with the standard's criteria, label use policies and usually to being able to guarantee a defined level of traceability.
(5) Traceability systems	Traceability systems are an integral part of certification schemes as they help to link a product to its origin and are key to support a sustainability claim related to a product. Traceability is ensured through the maintenance of a so-called chain of custody, which is 'the custodial sequence that occurs as ownership or control of the material supply is transferred from one custodian to another in the supply chain' (ISEAL, 2016, p. 2).
(6) Capacity building	Some schemes also involve capacity building elements, i.e. including knowledge transfer on best practices in farming to support smallholders to increase their income.

Based on Komives & Jackson (2014, p.5) and Tröster & Hiete (2018, p.2)

3.1.4 Key actors

The "key feature of a [third party] certification [scheme] is that inspections are carried out by independent **[certification] bodies** […] in accordance with standards laid down by external organisations" (Albersmeier et al., 2009, p. 927). This third party is involved to ensure independence, objectivity and credibility of results (Mori Junior et al., 2016, p. 587).

Figure 3-1 - Main actors in a third-party certification scheme



Source: Own elaboration

Standards are usually defined by the **scheme owner.** This organisation determines the objectives and scope of the certification scheme, as well as the rules for how the scheme will operate and the standards against which conformance will be assessed. In most cases this is the standard setter, however it may also be an assurance provider, a governmental authority, trade association, group of assurance providers or other body (ISEAL, 2013). To ensure impartial outcomes, the scheme owner is usually not allowed to interfere with the certification process in any decision-making capacity[4].

In addition to following the procedures set by the scheme owner, a certification body (CB) also needs to conform with a set of generic standards pertaining to good auditing practice and competence (see for example ISO standard 17021 (2015)). To formally demonstrate its ability to perform audits, the certification body needs to undergo an assessment process called accreditation, conducted by an **accreditation body**. These accreditation bodies (AB) provide formal assurance that a CB and its staff fulfil the general requirements to conduct audits and demonstrate competence to audit against a specific standard (see for example ISO standard 17011 (2017)). Accreditation, certification and standard setting usually follow processes defined by standards and guides developed by the International Organization for Standardization or the ISEAL Alliance[5].

3.1.5 Certification process

The third-party certification process (see Figure 4) commences once a producer applies for certification to a scheme owner. The latter provides this potential client with a list of accredited CBs. The applicant company chooses a CB with which it usually signs a contract that details the CB's scope of work. It is important to note that the certification process is paid for by the client company, thus CBs may not only be chosen based on their reputation but also based on price (Hatanaka et al., 2005, pp. 362–363). If the client organisation successfully completes the certification process, then it is awarded a certificate by the CB. This certificate and related labels can then be used in supply chain and consumer communication according to the scheme owner's rules.

Figure 3-2 - Simplified third party certification process

Source: Own elaboration

In general, certification covers two areas that may be addressed by separate standards within the same certification scheme. Standards for production, processing and manufacturing itself prescribe environmental or social production practices that need to be respected to achieve certification. There is also supply chain certification that is intended to ensure product

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[4] While ISO standard 17067 for 'Conformity assessment – fundamentals of product certification and guidelines for product certification schemes' (2013) allows certification bodies to act as scheme owner, commonly used references for sustainability certification schemes, like the GSSI Global Benchmark Tool (2015) and the FAO Technical Guidelines for Aquaculture Certification (2011) do not allow this to ensure the scheme owner's impartiality

[5] The ISEAL Alliance is a membership organisation for certification schemes like the Forest Stewardship Council, Rainforest Alliance, Roundtaible for Sustainable Palm Oil and others. In addition to meeting standards set by ISO, ISEAL members also align with the ISEAL Codes of Good Practice for standard setting and other activities (ISEAL, n.d.).

traceability and integrity along the supply chain. This so-called chain of custody (CoC) certification ensures that actors handling or processing certified commodities maintain their integrity by following procedures that avoid, for example, mixing with other non-certified products. Maintaining this chain of custody can make up a significant part of the overall certification cost a product incurs until it reaches the end customer or consumer. Some scheme owners set separate CoC standards while others integrate them in production and processing standards. See Figure 2.1 for a simplified supply chain that is covered by product and chain of custody certification.

3.1.6 Core functions of certification schemes and standards

Food commodity certification can serve a variety of purposes that may depend on the party driving the certification effort. NGOs use it to create alternative ways of production and consumption by incorporating more sustainable practices in existing systems to ultimately promote responsible production and resource stewardship (Hatanaka et al., 2005, p. 364). This may take the form of capacity building efforts where producers are actively supported on their way towards improved practices and certification (Hidayat, Glasbergen, & Offermans, 2015). It may also happen through increased pressure created by a certification schemes' market coverage and certification processes that encourage stakeholder input. A good example is the World Wildlife Fund for Nature's (WWF) work with MSC certification, strongly advocating it to retail and fisheries, but also using the certification processes to raise concerns about the sustainability of specific fisheries.

Retailers rely on certification as a strategic instrument for chain coordination, structuring market access and risk management as well as to ensure consistent implementation of standards regardless of product origin. TPC helps them reduce risk and risk assurance cost by shifting liability to the certification scheme and the monitoring costs involved to suppliers. Certification also helps them reduce transaction cost through, for example, lower supplier search cost (Hatanaka et al., 2005, pp. 356–360). This may result in certification becoming more of a market access requirement for producers, rather than an opportunity for differentiation (Blomquist, Bartolino, & Waldo, 2014, p. 692).

This non-exhaustive overview of how different groups are using certification points towards several general functions of sustainability certification schemes. The following section briefly discusses them and highlights those that are expected to benefit most from BCT driven applications. This mostly concerns the functions that rely on, or are responsible for, efficient and trusted information exchange.

Behavioural change

Driving behavioural change and providing credible assurance of compliance with defined performance (Meuwissen et al., 2003, p. 54) or process standards (Mori Junior et al., 2016, p. 580) are among the most relevant features of certification schemes. Gulbrandsen (2010, p. 22) emphasizes their role in "create[ing] rules and governance arrangements that contribute to a realignment of incentives governing resource management and use". It should however not be deduced from this that all actors engaging in certification are changing their practices. Some are already operating in conformance and simply wish to use a scheme to provide independently verified claims to their customers (Gulbrandsen, 2009). Overall, Giovannucci & Ponte (2005, p. 286) highlight the role of certification in advancing the sustainable development paradigm, driving conservation, economic viability of producers, and social responsibility.

Certification schemes with sufficient market support also put pressure on laggards or even an entire sector by rewarding good performers with better market access (Auld & Gulbrandsen, 2010, p. 97). The ability to drive behavioural change made certification an important tool in global value chain coordination (Bush & Oosterveer, 2015, p. 1865), but also an entry point for stakeholder pressure (Gonzalez-Padron, 2016, pp. 23–24). Engaging in a certification process often creates increased transparency (Gupta, 2008, p. 2) and benchmarks that stakeholders can apply to review a producer's practices. The credible threat of losing certification in the case of non-compliance has become a serious economic incentive to adhere to standards in a number of industries. Nesadurai (2018, p. 222) reports that when Indonesian palm oil giant IOI's Round Table for Sustainable Palm Oil (RSPO) certification was suspended, the company's stock market value dropped by 10% with buyers threatening to cut sourcing relationships. IOI's measures to address the non-conformities eventually led to certification being regranted after sufficient evidence was presented to RSPO (RSPO, 2018).

Reducing information asymmetry

Information asymmetry is a particularly challenging issue for credence goods (Dorr & Grote, 2009, pp. 545–547). Globally spread value chains, with disconnected producers and end customers, exacerbate the challenge of providing credible signals to markets (Anders, Monteiro, & Rouviere, 2007). Certification schemes are often used in situations of missing public regulatory enforcement and mistrust in suppliers to adhere to sustainable practices. In these instances, certification provides verified information that might otherwise not be available to buyers and consumers.

Standards and schemes begin structuring and determining market access when buyers start using certification to develop sourcing criteria and to identify suppliers (Giovannucci & Ponte, 2005, p. 286). This reinforces pressure on producers to adapt sustainable practices, but potentially also excludes those not able to make the necessary changes and investments. This particular issue is often raised in connection with small-scale producers (Mori Junior et al., 2016, p. 582).

Albersmeier et al. (2009, p. 928) postulate that, depending on the robustness of the relevant certification scheme, assurance of product quality can be provided to such a degree that they become experience goods. This means that their qualities can be assessed with certainty by viewing a certificate or label. This view is supported by Roberts (2013, p. 124) who sees the inherent challenge of the credibility of credence good related information nearly resolved through training and accreditation of competent certification bodies. Credible customer and consumer communication are thus a second core function of certification schemes and provide a remedy to information asymmetry in global value chains (Giovannucci & Ponte, 2005, p. 289). This mechanism also helps reduce transaction (Caswell, Bredahl, & Hooker, 1998) and coordination cost (Giovannucci & Reardon, 2000, p. 5). This is achieved by reducing search and control costs for buyers as certification helps identify and avoid the social and environmental costs that others bear (Roberts, 2013, p. 118).

Traceability

The credibility of any certification scheme and its on-product label are inseparable from the robustness of the underlying chain of custody (CoC) system.

The CoC needs to ensure that a defined level of traceability (see Table 3-3) is maintained by all custodians handling the product. The particular importance of an impeccable chain of custody becomes obvious when considering that many certified products are imported from regions where unsustainable practices are common, law enforcement is weak and where price and demand might incentivise illegal substitution of certified with non-certified products (Duggan & Kochen, 2016, p. 30).

Traceability is understood as "the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications." (Olsen & Borit, 2013, p. 148). For certified products this means that they can be traced back through a value chain (Rueda, Garrett, & Lambin, 2017, p. 2484), identifying all actors that handled a particular product or product type (Mol & Oosterveer, 2015, p. 12259).

Traceability requirements are either defined through separate (examples can be found in: MSC, 2015; RSPO, n.d.) or integrated (example: BAP, n.d.) CoC standards that cover the relevant production stages and define the level of traceability granularity that is to be respected in accordance with the final claim. Beyond ensuring that accurate product provenance information is passed along the chain, these standards also define requirements for handling certified products. Four traceability types as shown in Table 3 are differentiated according to Mol & Oosterveer (2015, p. 12263). Some examples are listed several times as certification schemes like RSPO allow their users to choose between different traceability systems (see Table 3-3).

Table 3-3 - Four types of chain of custody certification

Type	Description	Examples
Identity preserved	• Initially used for GMO/non-GMO segregation • Individual products or batches stay physically segregated and individually traceable to origin • Costly and thus only used where required by standard or customer • More likely to be used where exposed "lead firms" are likely to be attacked by campaigns and thus require more direct control over production	RSPO, EU organic, GlobalGAP
Segregation	• Physical separation of non-/certified products • Specific provenance (i.e. farm) is not guaranteed	RSPO, MSC, ASC, GlobalGAP
Mass balance	• No separation of non-/certified products • Buyer has no guarantee that he buys certified products • Verification that the certified quantities of produced and sold products match at the supply chain level	RSPO, Rainforest Alliance, FSC, BONSUCRO
Book and claim	• Certificates for certain production quantities can be bought and applied to non-certified products • Like in mass balance the quantity of sold certificates needs to match actual production • No physical supply chain is established, meaning that products for which certificates were bought usually do not contain certified inputs	RSPO, BONSUCRO

Source: Own elaboration based on Mol & Osterveer (2015), BONSUCRO (2016), MSC (2015), RSPO (n.d.)

While the flexibility provided by different approaches has helped to quickly expand the reach of certification, it also comes at a cost. Systems that do not segregate (i.e. mass balance) can have considerable time lag for volume reconciliation at supply chain or scheme level.

According to ISEAL (2016, p. 5) this can take up to a year, which is worrying as volume reconciliation is still considered an important tool in ensuring supply chain integrity.

Furthermore, certification schemes and their traceability systems may support a company's compliance with legal requirements. Examples include proof of fulfilling EU food traceability requirements (Rival, Montet, & Pioch, 2016, p. 3) and due diligence requirements, as defined by the EU timber regulation (Gavrilut et al., 2015) and the US Seafood Import Monitoring Program (NOAA, 2017).

The traceability components of certification schemes are of increasing importance. Consumer demand for information about product provenance and production practices emphasizes the need for the availability of trustworthy information (Duggan & Kochen, 2016, p. 34). In reaction, a growing number of multinationals commit to 100% traceable supply for commodities such as tuna, cocoa and palm oil with certification playing an important role (Nesadurai, 2018, p. 220; World Economic Forum, 2017).

Other

Beyond the above-mentioned core functions, certain certification schemes also put other causes high on their agenda. These will be briefly mentioned to provide a complete overview. However, as the immediate impact of BCT on these functions is expected to be rather limited, they will not be addressed further in the results section.

Price premiums are a recurring theme across many supply chains attempting certification against various schemes. However, only few certification schemes, like Fair Trade, explicitly include producer targeted premiums in their objectives (FLO, n.d.). While premiums can be significant for various organic and sustainably certified products, variations can be significant (Giovannucci & Ponte, 2005, p. 290). It is often described as more of an effect of improved market differentiation (Giovannucci & Ponte, 2005, p. 286; Nadvi & Wältring, 2004, p. 2) and segmentation (Giovannucci & Reardon, 2000, p. 2), where the benefits often remain at retail level (Blomquist et al., 2014). Another income-related effect is rising revenue thanks to better production practices and increased yields that are often facilitated through scheme-related training (Nesadurai, 2018, p. 215).

Finally, many certification schemes are built on multi-stakeholder governance approaches that aim to create opportunities for representation or at least participation of all affected stakeholders. Schemes like RSPO have thus also helped foster dialogue on sustainable practices (Rival et al., 2016, p. 8) as well as improved collaboration (Mori Junior et al., 2016, p. 384)

3.1.7 Criticism and challenges

This section focuses on three main areas of criticism towards sustainability certification schemes: standards and implementation, auditing practices and supply chain integrity. They have been identified as major areas of academic and practical concern. The author acknowledges that further issues, like small holder accessibility (Gulbrandsen, 2010, p. 28), are also discussed frequently.

Standards and implementation refer to the setting of certification criteria, the standard content, and their implementation and monitoring of continued compliance. Certification of unsustainable practices is a commonly raised issue (Froese & Proelss, 2012; Jacquet et al., 2010; Ponte, 2008). Criticism ranges from weak (Mighty & Brainforest, 2016, p. 59) and vague standards (Ruysschaert & Salles, 2014) to misinterpretation, disregard or too flexible interpretation of standards in the certification process. An example can be found in Christian et al. (2013, p. 15). The authors discuss a certification body's positive certification decision for a fishery that was not in compliance with national law despite "respect for law" being a requirement by the scheme. When stakeholders objected, the scheme owner replied by stating that "respect for laws is different to compliance with laws and this part of the indicator does not require that a fishery management system be in perfect minute-to-minute compliance with every single piece of substantive or procedural law that may govern a fishery". Various authors challenge certification schemes across different commodities for lacking consequences for evident non-compliances (Mori Junior et al., 2016, p. 586; Ruysschaert & Salles, 2014). Laurance et al. (2010, p. 378) provide several examples of RSPO certified oil palm plantations that had been built on land that was deforested after the grandfathering date defined by the RSPO standard.

Another mentioned shortcoming is context-related ineffectiveness of certification schemes when it comes to driving improvement. Part of the reason is that they appear to attract mainly those producers whose operations are already in de facto compliance (Gulbrandsen, 2010, p. 36). This criticism of lacking or little tangible improvement (Gulbrandsen, 2009) is supported by scholars who criticise insufficient outcome monitoring and demonstration of impact towards stakeholders (Mori Junior et al., 2016, p. 583).

Independent auditing is the backbone of credible certification but can incur significant costs (Ponte, 2008, p. 167; Rival et al., 2016, p. 7) that need to be justifiable. Organisations that wish to be certified can usually choose from a list of accredited certification bodies (CB). Selection parameters include trust in a CB's capabilities but also cost and expected stringency. One reproach is that the resulting dependence and competition between CBs may result in a race to the bottom in terms of cost and lenient auditing behaviour (Albersmeier et al., 2009, p. 930). Competition and pressure for product availability are said to potentially lead to a lowering of standards or inconsistent application across audit processes and firms (McCarthy, 2012, p. 13).

Audit duplications are not a challenge specific to third party certification: they are at least equally frequent in direct supplier auditing against buyer codes of conduct. Welford & Frost (2006, p. 169) reported companies that totalled over 50 audits per year with significant overlap. Duplication does not necessarily mean that the same audit protocol is applied twice to the same supplier, but that audits by different buyers or certification schemes overlap. Sharing of auditing results to avoid these overlaps has been debated for a long time but efforts for effective sharing and reduction of audit burden have not yet succeeded on a broad scale (Schwarzkopf, Adam, & Wittenberg, 2018). Furthermore, several schemes require in-person auditing of all actors along a certified supply chain, even if they do not physically handle a product. This practice is said to increase cost while not really enhancing supply chain integrity.

Finally, **audit effectiveness** is called into question. Especially for chain of custody audits, certification bodies have limited time available and a potentially large number of sites to inspect. Familiarising with the audited organisation and accessing all relevant documentation may take time away from the actual site auditing, increasing the likelihood of not detecting non-compliances. Similar concerns are raised by critics of 'check-list based auditing', highlighting that rigid audit protocols may be easier to deceive than risk based approaches focusing on a flexible set of priorities determined by the auditor (Albersmeier et al., 2009).

Supply chain integrity is a sparsely addressed topic in academia. This includes ensuring that certified volumes entering the supply chain match what is being sold as certified, noting that companies may choose to not sell something as certified, even if it is. Prominent practitioners such as the former executive director of the Forest Stewardship Council and current executive director of the Sustainable Agriculture Network, Andre de Freitas went as far as calling "chain of custody certification […] a myth" (Freitas, 2014). Several factors contributed to this statement. A company, for example a coffee roaster or saw mill, needs to undergo certification against the relevant certification scheme's (i.e. Rainforest Alliance for coffee or FSC for timber) chain of custody standard to prove that its management system and practices are ensuring a defined level of traceability. Common requirements include that evidence for matching volumes of certified products in the form of receipts for in- and outgoing shipments can be presented. The audited company is thus required to identify and disclose suppliers and buyers to the CB, satisfying the broadly applied requirement of one step forwards one step backwards traceability. Supply chains for a certified product are often made up of many companies and span several borders. The companies in a supply chain are very often not audited by the same CB, making it impossible to verify that a buyer registered the correct amount of certified material and not more. Such fraud aiming to pass on conventional as certified material can only be effectively prevented if volumes are reconciled at supply chain level. This does not happen systematically within most certification schemes. The fact that several CBs are providing CoC certification in the same supply chain, without sharing information, makes it relatively easy for deceptive actors or errors to pass unnoticed. This is sometimes being referred to as double-spent problem, meaning that certificates or proof for certified material is used several times, including for non-certified products being sold into a certified supply chain. Lacking systematic volume reconciliation procedures enable CoC fraud and currently require costly and time consuming manual traceback and volume reconciliation exercises. Relevant cases are found in certification of sustainable fisheries (MSC, 2014), cocoa (BASIC, 2016), forestry (NEPCON, 2014), palm oil (Nesadurai, 2018, p. 210) and others.

Growth of small-scale production can also represent challenges for traceability in terms of dealing with a high number of supply chain entry points. In Indonesian palm oil production major deforestation impacts are associated with strong smallholder growth, stirring up fears that this may result in illegal products entering certified supply chains (Nesadurai, 2018, p. 210). Similar concerns were raised over cocoa imports from Côte d'Ivoire, where certified production volumes increased significantly while smallholder plantations moved into protected forest areas (BASIC, 2016).

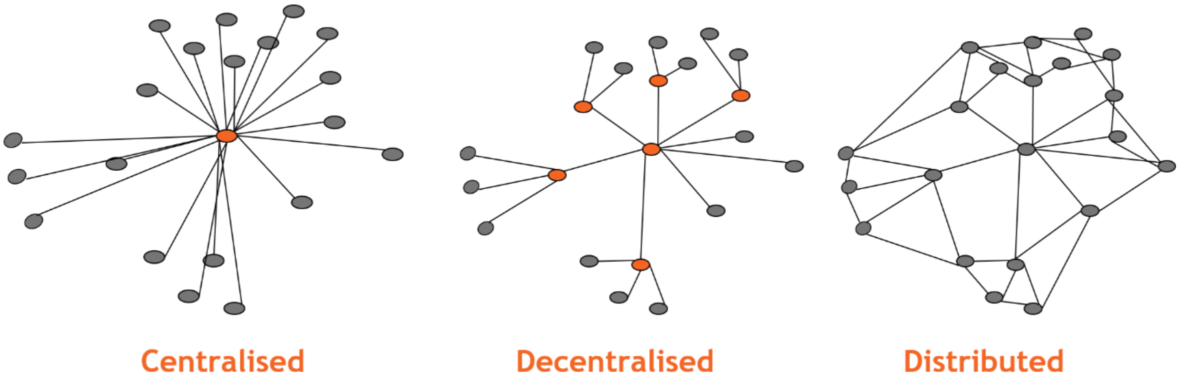
3.2 Blockchain

This section introduces blockchain technology (BCT) and examples for its application. It assesses currently available literature and then bridges to the potential of BCT for (sustainability) certification.

For centuries, the exchange of valuable goods, including financial transactions, required a trusted third party to register transactions and changes of ownership. Typical trusted intermediaries include banks, patent offices and land-registries that used paper ledgers to record a transaction. With the introduction of computers, computer networks and later-on the internet, many of these processes were digitalized. This ultimately resulted in greater transaction speed, while adding the challenge of preventing double-spending of monetary amounts in digital accounts. While a physical coin cannot be spent twice by the same party, money from a digital account can be spent multiple times if no appropriate control mechanisms are in place to avoid that account holders create money from nothing. This highlights the importance of banks as trusted intermediaries to prevent the double-spent problem as long as financial transactions continue to rely on a single central digital ledger. A central registry of transactions that would not be controlled by a single authority would be open for fraud by deceptive participants. Perceived flaws of operating with a third party include that all participants need to trust the third party to register and represent all transactions truthfully and obliged to cover the cost for the third party's services (Hanson, Reeson, & Staples, 2017, pp. 2–3).

Decreasing cost and increasing power of information processing infrastructure made new ledger technologies available to large scale applications. This includes the introduction of distributed ledger technology (DLT). Distributed electronic communication is not a new concept and was initially introduced to strengthen the resilience of communication networks against points failure as shown in Figure 3-3 (Baran, 1964). But the means to apply this to databases in a way that is still limited but accessible to the average internet user have become available only recently. With DLT, every participant in a peer-to-peer network maintains a local copy of a ledger to which every participant in a public permission free network can add transactions.

Figure 3-3 - Communication network structures



Dots represent nodes in a network. Orange dots represent nodes whose failure would impact the entire network through (partial) loss of information access. Source: Recreated after Baran (1964)

Once a node enters a new transaction it is broadcast to the entire network of nodes that can then view and verify the new transaction. Combined with appropriate consensus mechanisms and encryption technology, this enables transactions with anonymous participants without the need for a third party. It also enables fault-tolerance and blocks malicious actors from tampering with the transaction history (Locher, Obermeier, & Pignolet, 2018, p. 3).

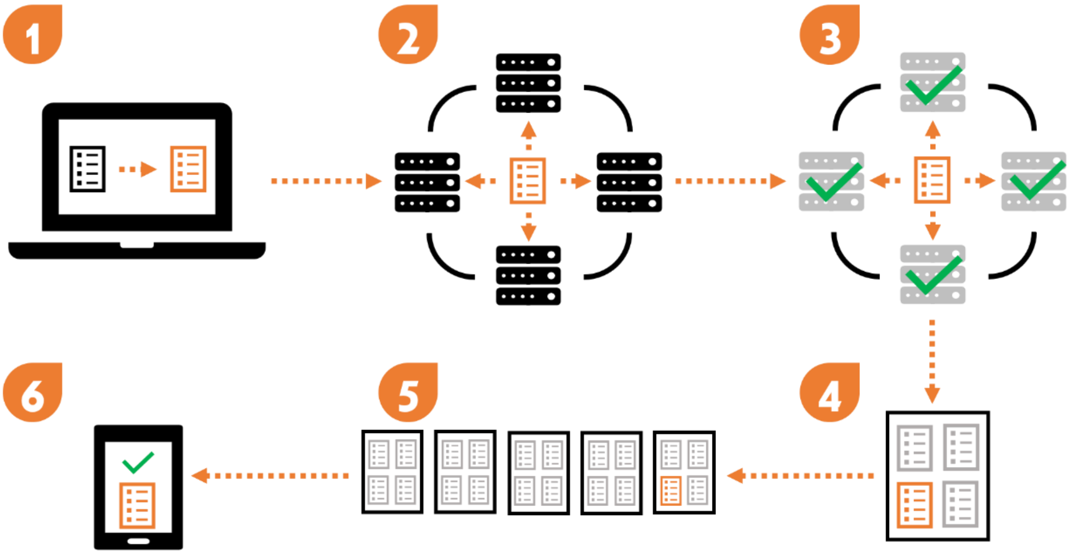
The first successful large scale application combining DLT, public private key cryptography and powerful consensus mechanisms was introduced with the cryptocurrency Bitcoin (Nakamoto, 2008). The main objectives behind the bitcoin blockchain protocol was to eliminate the need for trusted intermediaries like banks to exchange digital property titles as well as anonymise transacting parties (Nakamoto, 2008, p. 1). Elimination of this trusted third party is required to prevent double-spending of digital funds and instate trust in the peer to peer systems that such fraud is effectively prevented (Notheisen, Cholewa, & Shanmugam, 2017, p. 426).

The Bitcoin blockchain enables secure transactions through several steps:

(1) Digital property titles, in this case electronic coins, are digitally signed with the owners' public signature as well as the recipients' public signature. This establishes an auditable trail of ownership (Nakamoto, 2008, p. 2).

(2) Double-spending of electronic coins is prevented by timestamping the data representing the coin and thus proving when and to whom it was transferred, preventing a party from using the same coin twice in separate transactions or reversing transactions (Nakamoto, 2008, p. 2).
(3) To add a new block of transactions to the distributed ledger, a node is required to solve a mathematical puzzle faster than the other network nodes to be eligible for a reward in form of cryptocurrencies. This requires a certain computational power and serves to create a secure transaction history that is protected by the computational power of the network (Nakamoto, 2008, p. 3).
(4) New blocks are broadcast to the network of nodes and will only be accepted if all included transactions are valid and not yet spent. The accepted block is then used by the network to attach the next block, making transactions irreversible and the record censorship resistant (Nakamoto, 2008, p. 3).

Figure 3-4 - Adding transactions to the blockchain



Source: Recreated after World Economic Forum(2018, p. 10)

Figure 3-5 describes in a simplified way how transactions are announced, verified and added to any blockchain. The process starts (1) when a user X requests a transaction and announces that transaction (2) to a network of connected computers that are referred to as nodes. The nodes then verify (3) that a transaction is valid. This usually involves comparing the requested transaction to their local copy of the network's transaction history to ensure that the account balance of user X actually allows the transaction in question. Once that transaction is confirmed it is (4) bundled into a block with other transactions (see also Figure 3-6) and (5) added to the blockchain. The transaction is then complete (6) and can be viewed by all that have access (or sufficient permission) to the network (World Economic Forum, 2018, p. 10).

The combination of a distributed database architecture and consensus mechanism therefore allows parties that do not have to trust each other to safely exchange value over an electronic system without depending on a central trusted oversight body, as tampering with the transaction history is prohibitively expensive (Notheisen et al., 2017, p. 426; Wüst & Gervais, 2017, p. 1). Under the Bitcoin blockchain's proof of work consensus algorithm, it would require repeating all previously done calculations and outpacing the rest of the network in solving the mathematical puzzle to append new blocks. This would only be possible if the attacker controls more than half of the involved computational power (Nakamoto, 2008, p. 3), a scenario that is highly unlikely in large and fast-growing peer-to-peer networks such as Bitcoin or Ethereum.

3.2.1 Key properties of BCT

The exponential growth of cryptocurrencies has created strong interest to apply BCT in various other economic sectors that are struggling with trust deficits and imperfect oversight. In this context, trust would usually be based on the assumption that participants behave as they should according to defined or implicit rules (Locher et al., 2018, p. 2). The growing interest seems to be rooted in a number of four key properties of BCT that include transparency, durability, immutability and process integrity (Wüst & Gervais, 2017, p. 2), explained in more detail below. Scholars also list privacy as an important property and advantage (Saberi et al., n.d., p. 4). However, it has been shown that triangulation of transactional data and addresses may enable identification of users despite public private key cryptography.

Transparency – Each node in a network maintains an identical copy of the blockchain that is updated as soon as any node adds an agreed transaction. This enables real time auditing of data, making the related activities highly visible (Dapp et al., 2017, p. 3), potentially even to everyone with access to the internet if the network is public. This public transaction history allows to retrace who owned what at what time and to whom it was transferred, making provenance visible to everyone (Abeyratne & Monfared, 2016, p. 4).

Durability – Decentralized networks enable durable, failproof storage Dapp, Balta, & Krcmar (2017, p. 3). The elimination of single points of failure, a concern often raised in relation to centralized databases, ensures that data is permanently available and protected against alteration (Abeyratne & Monfared, 2016, p. 4). The distribution over many nodes practically eliminates the risk of information not being available and simplifies data recovery. These benefits come at the expense of increasing complexity and processing overhead cost (Notheisen et al., 2017, p. 437).

Immutability – Blockchain technology builds on consensus mechanisms requiring a majority or some particularly powerful network participants (Wu et al., 2017, p. 3) to validate transactions before they are added to a blockchain (Wüst & Gervais, n.d., p. 1). The grouping of timestamped transactions into blocks and their cryptographic connection makes the blockchain quasi immutable as it is append-only (Dapp et al., 2017, p. 6) and "allow[s] users to operate with the highest degree of confidence that the chain of data is unaltered and accurate" (Abeyratne & Monfared, 2016, p. 4).

Process Integrity – Some blockchains, like Ethereum, offer programming language to develop software that is automatically executed when certain conditions, for example a specific transaction on the blockchain, are fulfilled. The open source nature of the code reassures users that actions are exactly and timely executed as defined in the relevant protocols, without the need for any further human intervention (Abeyratne & Monfared, 2016, p. 4).

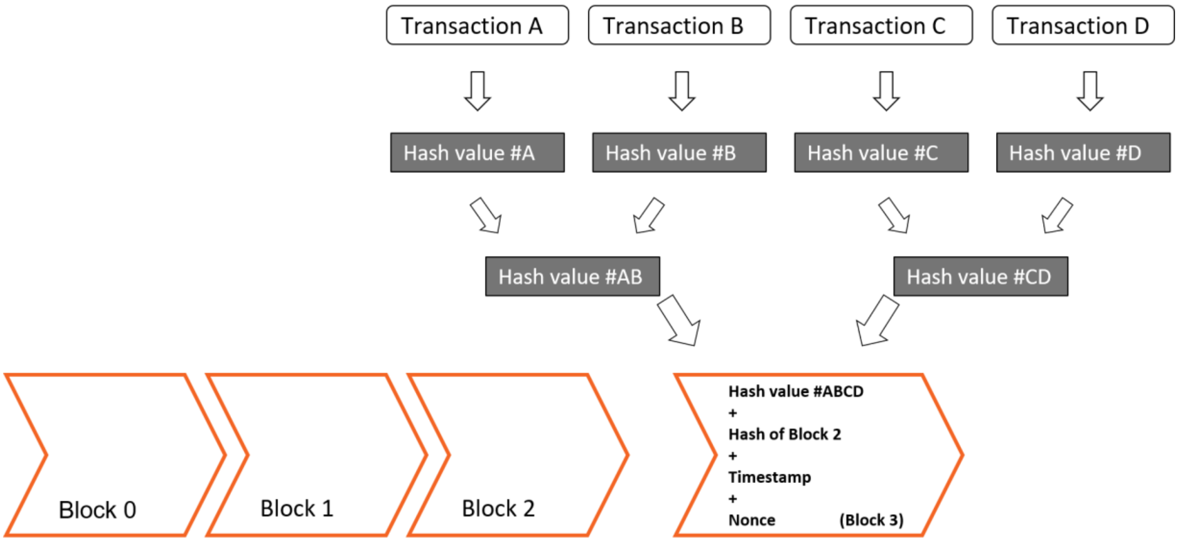
3.2.2 Architectural choices

While the Bitcoin blockchain only allows storage and generation of transactional data, more recent projects such as Ethereum (Buterin, 2014) and Hyperledger (Linux Foundation, 2018) offer programming languages that enable self-executing pieces of code, so-called 'smart contracts'. **Smart contracts** enable automated actions (e.g. a payment to a specific account) following a pre-determined commonly agreed logic (Di Ciccio et al., 2018, p. 57; Locher et al., 2018, p. 2). Like a vending machine that dispenses a product as soon as a previously agreed amount of money was inserted, a smart contract can for example automatically initiate a transaction of funds once the contract requirement was fulfilled. This bears the potential to significantly speed up transactions of physical goods traded in a blockchain environment by automatically clearing a shipment once valid proof for required documentation and permit is presented (Castillo, 2018). Similar logics can be applied to payments as a product travels along a supply chain.

Authors differentiate between two sets of actors in a blockchain network: writers and readers. Writers are directly involved in the consensus protocol and help to grow the blockchain by writing state to the database (Wüst & Gervais, 2017, p. 1). In the context of Bitcoin or Ethereum these writers are referred to as miners. Readers only transact or read (i.e. analyses; audits) content on the blockchain, but do not participate in the consensus protocol (Wüst & Gervais, 2017, p. 1).

Consensus mechanisms are needed to artificially create barriers against false information by inflating the cost for such fraudulent actions (Notheisen et al., 2017, p. 427) or attributing validation power to certain actors. A number of alternative consensus mechanisms have been proposed. "Proof of work", as used by Bitcoin and Ethereum is based on all validating nodes entering in a competition to solve a mathematical puzzle with the aim to arrive at a number below a previously defined target value. This is done by taking information of the previously agreed block, the transaction records that still need to be added to the blockchain and a random number called "nonce" as input for a so-called "hash algorithm" (see Figure 3-6). This algorithm transforms any data input into a unique alphanumeric string that will always have the same number of characters, regardless of the input. This output is called a hash. Any change to the input will result in a completely different hash that cannot be predicted.

Figure 3-5 - Adding new blocks to the blockchain



Source: Recreated after Pisa & Juden (2017, p. 40)

However, two nodes running the same information through the same algorithm will produce the same hash. The first node to guess the right input value to arrive at a hash value below the predetermined target announces their solution to the network. As everyone can see the information that was used they are able to run the same calculation and quickly confirm the validity of the proposed block and the included transactions (Nakamoto, 2008, p. 5). The high security level that proof of work offers to large networks comes at a cost: it reduces transaction speed and requires significant computation resources that translate into high energy needs (Gao et al., 2018, p. 240). The combined estimated annual energy consumption of the Ethereum and Bitcoin blockchains now exceeds that of Belgium (Digiconomist, 2018) and has fuelled a global race for cheap energy to build up new computation resources (World Oil, 2018).

An alternative consensus mechanism is proof of stake (PoS). A defined accumulation scheme determines how participants aggregate stake in a network. This can be based on different parameters, including how long a participant has held a certain amount of currency. Those nodes that have sufficient stake in the network are eligible to be transaction validators. This approach has the potential to generate blocks much faster than proof of work as only a limited number of nodes is involved in the process, however, it can also result in situations where everyone or no-one has enough stake to generate blocks, potentially making the system unstable (Gao et al., 2018, p. 240). Concerns were raised that PoS might also result in a greater risk for transaction history to be forged (Ethereum Wiki, 2014/2018).

Private blockchain networks usually operate under different conditions than public ones and favour the use of lighter consensus mechanisms. Participants are known and at least some are trusted. This can be argued to reduce security risks and has been used as an argument to propose less decentralised consensus mechanisms. Proof of authority is one example where appointed nodes validate transactions and add them as new blocks to the blockchain, significantly increasing the overall transaction capacity (Parity, 2018).

A further important design choice is whether a blockchain is open or permissioned and public or private:

(1) The differentiation between public or private refers to the question whether a blockchain is publicly accessible or not.
(2) The differentiation between permissioned and open refers to whether anyone is excluded from transacting or writing on a particular blockchain. This differentiation is valid for both open and permissioned blockchains.
(3) Blockchains that are permission free (open) and mostly public, like the one used for Bitcoin, allow everyone with access to the internet to read and write and there is no central entity that manages participation (Wüst & Gervais, 2017, p. 1).
(4) Permissioned and usually private blockchains can only be accessed by authorized entities that are granted reading and/or writing access (Wüst & Gervais, 2017, p. 1). Access is provided by a central authority (Wüst & Gervais, 2017, p. 2), for example a certification body that manages a supply chain network (Saberi et al., n.d., p. 4). Private blockchains may not offer the same levels of transparency and security, which is why hybrid solutions have been proposed where certain processes, like validating non-confidential transaction data, are run on a public blockchain like Ethereum or Bitcoin, while sensitive information is kept on the private consortium chain (Enterprise Ethereum Alliance, 2017).

There are many other relevant design decisions (see for example Xu et al. (2016, p. 4)), but choice of consensus mechanism and accessibility of the blockchain seem to be the most basic and relevant aspects for supply chain management and certification as they significantly determine cost and complexity, as well as trust in available solutions. Both aspects are fundamental to scalability of blockchain solutions in potentially data-intense supply chain contexts and with regards to concerns about sharing commercially sensitive supply chain information.

3.2.3 Challenges

While there have been thefts of cryptocurrencies, these security breaches were not linked to corruption of a blockchain itself but to the applications and services built around it. What allowed the theft of cryptocurrencies like Bitcoin were poor design of applications using blockchain, like issues with cryptocurrency wallet security (Folkinshteyn & Lennon, 2016, p. 226) or faulty smart contracts run on a blockchain (Ge et al., 2017).

Changing transaction history itself is quasi impossible and becomes more difficult as networks grow as it would require a so-called '51% attack'. In this scenario the attacker has to control more than 50% of the total computing power in a network to make the network accept his version of the blockchain. The risk of such an attack is relatively low with blockchains like Ethereum and Bitcoin as the currently dominating consensus mechanisms are making it prohibitively expensive. But this security comes at a cost. Transaction speed is severely limited as only comparatively few transactions can be validated per second (Notheisen et al., 2017, p. 427). This limits the usefulness of certain blockchain formats for large-scale supply chain applications that would involve high numbers of transactions.

The censorship resistance of transaction history on a blockchain may be a further concern. Wrong orders, faulty deliveries and other erroneous transactions may need to be reversed. While this is theoretically possible by sending back the delivery and registering this as a new transaction on the blockchain, it might also increase reluctance of actors to join such a network. This is because errors that are permanently visible to all other participants may lead them to staying away from certain supply chain partners.

Finally, privacy concerns are a frequently raised issue. While the employed public private key cryptography is supposed to guarantee anonymity, triangulation of transactional and address data has enabled the identification of participants. This is a concern when public blockchains are used and participants, like in the case of confidential supplier networks, are concerned with losing their competitive advantage (Wüst & Gervais, 2017, p. 4).

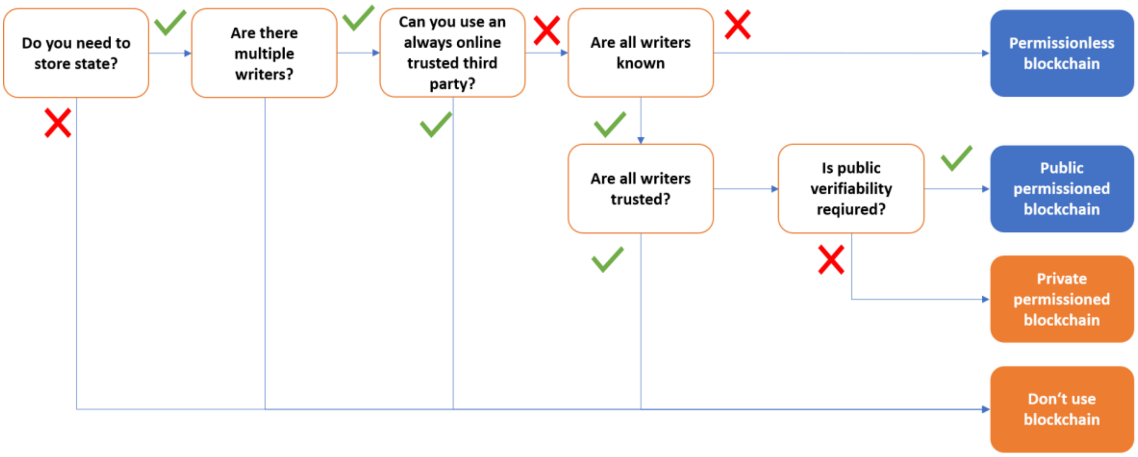
3.2.4 When does it make sense to use blockchain?

Notheisen et al. (2017, pp. 437–438) define three preconditions for a BCT based application to provide added value compared to centralised database systems:

- **Actors have conflicting interests and motivations,** which provides a strong incentive to participate in a truth revelation process.
- **Information asymmetry** exists, if a transaction involves for example at least one party with private information, and a willingness to address this exists as well.
- **Several conflicting parties have writing access,** otherwise there would be no need for a consensus protocol.

The latter hints at the crucial question of whether a trusted third party exists in a given interaction. According to the widely cited decision framework (see figure 3-7) by Wüst & Gervais (2017, p. 2), using a blockchain "only makes sense when multiple mutually mistrusting entities want to interact and change the state of a system, and are not willing to agree on an online trusted third party".

Figure 3-6 - When does it make sense to use blockchain?



Source: Recreated after Wüst & Gervais (2017, p. 3)

Considering this framework from a purely technical perspective, supply chain applications are expected to require either privately permissioned or no blockchains at all (see orange boxes in Figure 3-7). Supply chain management requires data storage, it involves multiple writers, but a trusted third party is not necessarily always online, and all writers are usually known but not necessarily trusted. Otherwise, there would be no need for any kind of certification (Wüst & Gervais, 2017, p. 4). In addition, they highlight the uncertainty about true product attribute reporting caused by possible weaknesses in connecting digital and physical identities, as well as erroneous data capture. The authors conclude that blockchain applications for supply chain management are of limited added value compared to centralised applications, as long as there is no broadly applied technology to securely connect digital and physical assets (Wüst & Gervais, 2017, p. 4).

Koens and Poll (2018) analyse blockchain technology application in a certified supply chain from a wider angle. They agree that the added value from a purely technical angle is limited as long as it serves merely as an unaltered digital record of audit and supply chain event history. This is especially so with regards to the reliance on a trusted third party, the certification body, which makes the technical need for a blockchain solution questionable in their view (Koens & Poll, 2018, pp. 7–8). However, Koens and Poll propose a wider set of non-technical drivers that may justify the application of BCT that include:

- **Philosophical beliefs**, focusing on a users' beliefs and convictions.
- **Network effects**, where the adoption is driven by frontrunners and curiosity.
- **Economic incentives** that highlight potential financial gain (i.e. consultancy services) or the prevention of potential financial losses, as well as the fear of missing out.

3.3 Blockchain, Supply Chains, and Certification

Blockchain technology is already being discussed, piloted and applied in various sectors beyond pure financial transactions. These include insurance (Ernest & Young, 2017), elections (Miller, 2018), aid distribution (Pisa & Juden, 2017; World Food Programme, n.d.), conservation (Eyholzer et al., n.d.) and local energy markets (Brooklyn Microgrid, n.d.).

The ability to create an immutable record of asset ownership in a low-trust environment has made supply chain management one of the most popular applications for BCT outside of finance (Nash, 2018). Kshetri (2018, p. 81) expects BCT to support the achievement of key supply chain management objectives, including:

- Timely distribution of products in the right condition and at the lowest possible cost;
- Risk reduction and prevention and reduction of related control cost, for example by allowing more targeted product recalls;
- Supplier evaluation and sustainable procurement.

Information-sharing is commonly seen as a critical element for supply chain performance (Ghosh & Tan, 2018, p. 4) and reliable information is indispensable to deal with objectives including consumer trust, supply chain transparency, product quality, fraud prevention, and food safety (Ge et al., 2017, p. 14). Achieving these objectives is becoming increasingly difficult as growing supply chain complexity in the form of actor numbers, product diversity and geographic spread (Ghosh & Tan, 2018, p. 5) leads to concerns around supply security and socio-environmental concerns (Abeyratne & Monfared, 2016, p. 1).

Current supply chain information systems often lack the capability to provide "validated, pseudo-real-time shipment tracking during the distribution phase" (Wu et al., 2017, p. 1), which would greatly improve supply security and support for example containing food safety related recalls (Yiannas, 2018, p. 47).

The importance of frictionless information flows is evident but remains largely aspirational in many areas of the food industry (Bhatt et al., 2016; Bhatt, Gooch, Dent, & Sylvia, 2017). This is partly caused by lacking adoption of commonly agreed standards[6] for recording and sharing traceability data that leads to low systems interoperability and data silos (Yiannas, 2018, p. 46). Various authors report slow information flows and traceability that is limited to one step forwards and backwards along the supply chain as common challenges (Gao et al., 2018, p. 238; Yiannas, 2018, p. 46).

3.3.1 Advantages

Proponents of blockchain technology consider existing tracking solutions to suffer from dependence on single data sources, lacking validation (Wu et al., 2017, p. 1), reliance on single data brokers that concentrate disproportionate power through data, and single points of failure (Abeyratne & Monfared, 2016, p. 2). Opposed to that, blockchain is expected to improve traceability, trackability, procurement functions, privacy and reduce resource use in supply chain management (Kshetri, 2018; Saberi et al., n.d.).

Traceability and trackability – BCT creates an immutable proof of ownership, existence, and integrity of a good and its related documentation (Crosby, 2016, p. 14). It may ensure that documents are not tampered with and enable their digital traceability (Deloitte & Riddle & Code, 2018). In line with these findings Kshetri observed first evidence for increased supply chain transparency and accountability (Kshetri, 2018, p. 80). According to Banerjee (2018, pp. 14–15) and Saberi et al. (n.d., p. 10) a BCT supported supply chain, fitted with internet-connected scanning technology, would enable secure tracking and a validated auditable trail that practically eliminates counterfeiting possibilities.

Procurement – Banerjee (2018, p. 11) assigns BCT a strong potential to resolve disputes on supplier invoices for delivered goods by providing an "ultimate truth". The records providing

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[6] Include brief explanation of these standards to highlight difference compared to sustainability standards

this ultimate truth could furthermore be used to conduct supplier benchmarking and share this information among peers.

Privacy – BCT application providers like Provenance also highlight the possibility to guarantee privacy of network participants and differentiated access to supplier information according to downstream needs and permissions (Provenance, 2015). The actually guaranteed level of privacy is however questioned as the triangulation of data sources may enable identification of users(Folkinshteyn & Lennon, 2016, p. 224).

Reduce resource use – Finally, the possibility of tracking resources and products in real time is considered to offer significant resource saving potential (Saberi et al., n.d., p. 10). This includes a broad spectrum of effects, ranging from reduced recall scopes to improved recycling (Kölner Verpackungstag, n.d.).

3.3.2 Challenges

The introduction of blockchain technology in supply chain management processes also faces several challenges. A few are briefly discussed hereafter to support the analysis of the potential impact of BCT on sustainability certification.

Data quality – Ensuring that only high-quality data is fed into the system is essential for any supply chain information system. The "garbage in equals garbage out" problem seems however to be reinforced by the immutability of confirmed records(Ge et al., 2017, p. 24). Detecting false information entry at the first supply chain step may not be a simple task and could result in creating unjustified trust in a seemingly tamper-proof system transporting corrupt information (Notheisen et al., 2017, p. 436).

Digital infrastructure – Deploying BCT along supply chains results in digital infrastructure requirements of which a few are listed below. Again, these are not BCT specific:

- The required stable direct or otherwise established internet connection might not be available everywhere, a concern raised in relation to remote raw material production (Abeyratne & Monfared, 2016, p. 9).
- Depending on the supply chain type, significant network bandwidth and computing power might be required (Banerjee, 2018, p. 25).
- Access to technology, like sensors and scanners to link the physical-digital divide (Saberi et al., n.d., p. 15), is required to reap the full benefit of BCT in certain supply chain applications but deployment may not be affordable (Abeyratne & Monfared, 2016, p. 9).

Trust – Various trust-related issues are relevant when considering BCT use in supply chains.

Successfully deploying BCT along a supply chain builds on the willingness and capacity to share data. While this is not a blockchain specific challenge, certain required information may be considered a source of competitive advantage, making some supply chain actors unwilling to share critical data elements (Saberi et al., n.d., p. 14). Developing trust in a blockchain solution to only reveal certain information to agreed actors, while maintaining anonymity towards others, is one of the biggest concerns from a supply chain management perspective (Banerjee, 2018, p. 26; Caro, Ali, Vecchio, & Giaffreda, 2018). Proposed solutions include the combination of public and private blockchains or cloud storage where only data the access requests are stored on a public blockchain. These solutions require however a careful trade-off between privacy and transparency to enable widespread adoption while maintaining the key advantages of the technology (Wu et al., 2017, p. 15).

Koens & Poll (2018, p. 9) argue that trust in currently used third parties goes beyond the data integrity and can thus hardly be replaced by a blockchain application. This concept of trust includes the confidence in a third party's competence to independently deliver various services pertaining to supply chain assurance that require human interaction. This is in line with Locher et al. (2018, p. 8) who consider that the physical-digital interface in supply chains will always require a trusted third party to verify that a specific product exists with determined qualities or that sensor technology works as it should.

3.4 Analytical framework

Building on the literature review and introduced concepts, an analytical framework reflecting key functions of certification schemes and underlying processes was devised. These are then further broken down into specific supporting functions. For each supporting function a common challenge or criticism questioning the ability of certification to achieve the listed objectives is identified. Finally, a hypothesis on how blockchain technology helps to address the issue is presented. It should be noted that only topics where BCT provides a hypothetical solution were included. Results from the conducted interviews and reviewed cases are presented in section 4.

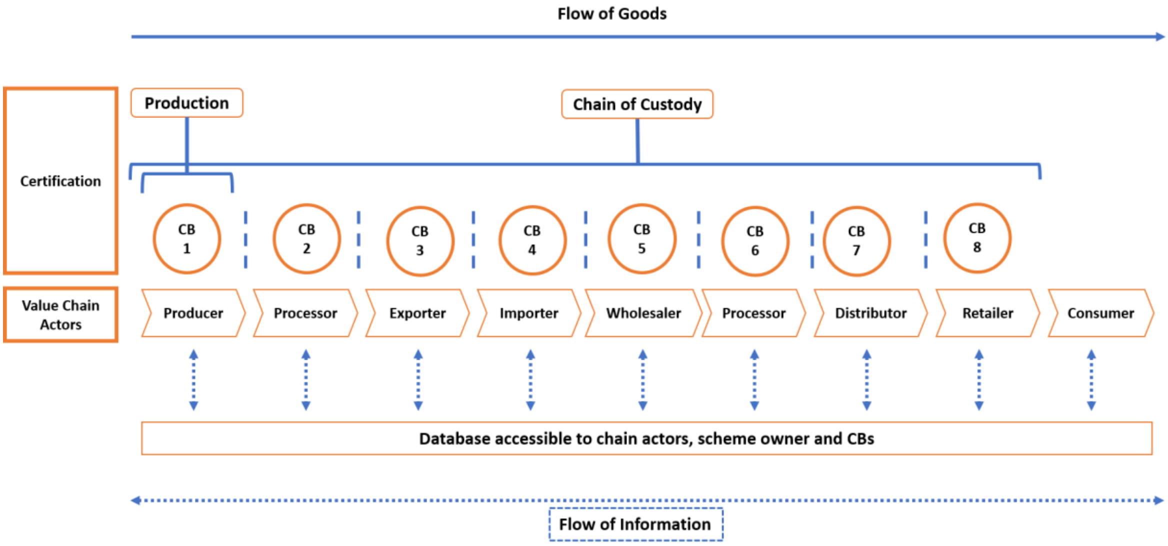
The framework addresses four areas within certification that, based on the literature review, are expected to see the most significant benefits from blockchain technology. Note that the fourth category (impacts on certification bodies) is addressed separately as it does not fit the objective, problem, hypothesis structure of the framework.

Chain of Custody – The core functions of a certification scheme's chain of custody are to ensure product traceability and thus support credible claims. The ability to fulfil these functions is dependent on sharing of accurate and trustable information at all supply chain steps. A combination of paper-based systems, fraud and disconnected controls may result in ineffective chain of custody verification and certification. Improving traceability by providing an immutable record of transaction history is frequently cited as one of the key impacts of blockchain technology on supply chain management (Banerjee, 2018, p. 14; Kshetri, 2018, p. 81) and can thus also be asummed to be of relevance for certification.

Additionally, the focus on BCT might advance the introduction of traceability databases along supply chains that could enable a continuous flow of information about a product's history up and down the supply chain. Figure 3-8 depicts how a potentially blockchain-based traceability database improves information flows and helps overcome the often-raised criticism of disconnected audits along a supply chain. This disconnect describes, for example, lacking volume control along a full supply chain that may result in non-compliant products entering a certified product flow. While the physical separation between certification bodies in a potentially cross border supply chain persists, its effects are mitigated by a trusted shared database.

Audit effectiveness and efficiency – Audits are a major cost driver in third party sustainability certification. The increased cost to producers and consumers needs to be justified through effective and efficient audits. This refers to their ability to satisfy the requirements of a scheme, to detect non-compliances, to avoid duplications across audits, and to focus on what is necessary to fulfil a scheme's requirements. Currently, audit effectiveness may be limited due to auditors requiring significant time to familiarise with a client, especially when documentation is incomplete or unclear. Certain supply chain actors may also not require an in-person audit when they do not physically handle products or have been audited against the same requirement under a different certification scheme. The possibility to "partition" standards, translate related audits into verified micro-claims and register them on a blockchain is only one potential avenue how BCT could help to focus audits and reduce costs (Kshetri, 2018, p. 80; Schwarzkopf et al., 2018).

Figure 3-7 - Supply chain with a potentially BCT based traceability database



Source: Author's own elaboration

Trust – Certification schemes have at least in part been established to create trust in product quality, despite a possible lack of trust between the trading parties. Third party certification aims to establish this trust by following a system of independent verifications and oversight and stakeholder involvement. Disregard for standards by producers, certification of unsustainable practices, and fraudulent introduction of non-certified products into certified supply chains threaten credibility and thus customer and consumer trust. The immutability and durability of BCT guarantee validity and reliability of represented information, potentially strengthening trust (Fowler, 2018, pp. 898–899). The availability of an immutable audit trail to all involved parties may also contribute to eliminate the double-spent issue. If certificates and production volumes are registered accordingly, the value of certificates may thus be increased through enhanced trust (Ge et al., 2017, p. 7).

Table 3-4 - Analytical framework

Topic	Scheme objectives	Challenges	Hypothetical BCT solutions
Chain of custody integrity	Produced and sold volumes match	Lack of digital infrastructure and systematic volume reconciliation at scheme level risk not detecting when more certified product is sold than produced	*H1 – Blockchain improves CoC integrity through shared distributed records and continuous data capture that enable immediate traceability and volume reconciliation at each step by connecting audits and traceability events across supply chain actors.*
	Traceability is maintained, and product substitution is prevented	(Un-) intentional substitution of certified products is difficult to detect with current infrastructure and systems	*H(2) The deployment of blockchain-based traceability systems will make the substitution of certified by non-certified products immediately detectable.*
Audit	Ensure effective audits	The limited time available to familiarize with a client and to audit, and lacking information on other supply chain actors, make a risk-oriented approach hard to implement	*H(3) Blockchain-based systems provide better access and trusted information before and during audits and help to drive a risk-focused audit approach.*
	Ensure efficient audits	There is overlap between certification schemes and thus supplier audits for different schemes checking the same issue are frequent	*H(4) Blockchain-based systems could enable the creation of micro-claims that reflect audit results for individual certification scheme requirements. This in turn would enable a modular auditing approach that reduces duplication of audits for companies working with different certification schemes and buyers.*
		A fair number of organisations in the supply chain would not have to be audited since they do not handle or alter the product	*H(5) The blockchain-enhanced transparency and immutability of once entered information could make certain on-site (CoC) audits of low-risk clients redundant as trusted information can be verified remotely.*
Trust	Provide credible market signals and reduce information asymmetry	Certification of non-sustainable practices and lacking chain of custody integrity (risk of non-certified products entering the chain) undermine credibility of claims and market signals.	*H(6) The censorship resistance inherent to blockchain technology, combined with unique digital product identities and the possibility to track and trace strengthens trust in claims.*

Source: Own elaboration

Certification bodies play a central role in third party certification schemes and the introduction of blockchain technology may significantly impact their operations. In addition to the analytical framework, collected data will also be assessed against the three hypotheses listed below to describe future operational requirements for certification bodies:

H(1) Blockchains in a supply chain network will result in new activities for certification bodies.

Such activities may include access management and authorization to certify the capability and reliability to supply accurate data.

H(2) Blockchains in a supply chain network will require new skills from certification bodies.

Depending on the role of a certification body in a blockchain supply chain network they might be required to audit a participant's IT infrastructure and data management processes.

H(3) Blockchains in a supply chain network will offer new business opportunities for certification bodies.

Deploying blockchain technology and the required digital physical interfaces may result in large data volumes that could be used to offer additional services to certified clients based on performance analytics. Clients might also request new traceability applications that could be provided best by certification bodies since they are familiar with client structures and have access.

4 Results

This section presents findings from the interview study and selected use cases along the previously introduced analytical framework, focusing on: (1) chain of custody integrity, (2) auditing, (3) trust, and (4) impacts on certification bodies. All presented contents are summarised and paraphrased interview responses unless marked otherwise. Exemptions are the presented use cases, which are based on documented project descriptions. The advent of blockchain technology in supply chain management and certification is a very recent phenomenon. Many reported findings therefore included expectations and not only experienced impacts. This involves accounts from organisations that conducted blockchain pilots as well as those that only evaluated the potential impact from an external perspective. Results are therefore reported in a three-tiered structure for each topic addressed in the analytical framework. The categorisation according to (1) expected impacts, (2) demonstrated impacts and (3) challenges helps the reader to differentiate between what interviews expect blockchain technology to have compared to what projects have actually already achieved and demonstrated. In addition, tabulated examples for specific use cases are provided to illustrate how expected or demonstrated impacts of blockchain technology relate to specific examples.

4.1 Chain of Custody

Chain of custody related impacts dominated across most pilot studies, early use cases and thus the reported interviews. Common challenges identified through the literature were confirmed. The fragmented chain of custody auditing approach with little to no communication between the different CBs active along one supply chain was repeatedly highlighted. This often results in CBs lacking access to complete supply chain data, limiting audit effectiveness when it comes to ensuring supply chain integrity and preventing issues like volume fraud, as reported by several interviewees. The negative impact of paper-based and therefore slow traceability approaches was similarly often mentioned. However, scheme owner representatives stressed that the perceived risk of fraudulent behaviour was much more significant than the breaches actually observed, nevertheless posing a significant threat to brand and label credibility.

WWF's Western Pacific Tuna Programme Manager has been involved in a blockchain traceability project for Fijian longline caught tuna since 2017. He expected that:

> *"blockchain will become the gold standard for chain of custody". "[Having] a blockchain traceability system in place, […] basically obviates the need for the chain of custody that the MSC currently maintains because why would you need an after the fact chain of custody audit when you can have instantaneous chain of custody audits as a result of blockchain?"*

Still, complex supply chains, where arguably the most value could be derived, have yet to see a full-scale implementation. Even very prominent use cases such as Provenance's tuna pilot have not fully developed an actual application that would prove the benefit to such supply chains and the related certification processes (Provenance, 2016).

4.1.1 Integrity

Chain of custody integrity is challenged by many factors that interviewees considered important in relation to the introduction of traceability databases and blockchain technology. The missing connection between audits of multiple connected actors in the same supply chain was a common theme. The current practice was described as individual and unrelated certification of each actor along a supply chain in the hope to provide assurance of a secure chain of custody through a yearly audit. This fragmented approach with certification bodies not exchanging audit findings was considered to create loopholes that increase the likelihood of auditors not being able to discover certain mistakes or fraud. Certification body Nepcon's traceability manager highlighted how this ultimately represents significant risk to those consumer facing brands:

> *"Every company in the supply chain is being checked in an isolated way. And this is not being pulled by auditors because there are different auditors from different countries not talking to each other. They are just going physically isolated to different companies and trying to check what is happening onsite, without this comparison of purchases and sales through the whole supply chain. And this is where a problem is lying and that is a big problem for those brands because suddenly they receive a message. There are some stakeholders, they caused some kind of investigation and it turns out that, for example, a sub-supplier or sub-sub-supplier was cheating."*

For certification schemes themselves interviewees identified the lack of a central party to verify volume consistency of certified product at supply chain and scheme level as problematic, particularly for schemes with very large market uptake. Much of the findings reported in Table 4-1 have to be considered expectations as the cited outcomes will only be measurable once applications have been used beyond pilots. However, the use of blockchain-secured traceability information in one case has been reported to have increased interest in the respective brand by ensuring the reliability of the provided information. Ensuring veracity of information fed into a blockchain-supported system was highlighted as challenge that will likely require further consistency checks like for place of production, time of production, and context factors, to avoid the immortalisation of false information.

Table 4-1 - Findings for BCT impact on chain of custody integrity

EXPECTED

- **Full supply chain visibility** will reduce the possibility for fraud to pass undetected
- **Near real-time volume reconciliation** will support fraud prevention.
- **Continuous and instant remote monitoring** will make non-compliances, like changing product attributes or replacing products visible outside of onsite audits.
- **Disintermediation** will create more direct links between producers and final customers by removing middlemen that do not add value.

DEMONSTRATED

- **Volume reconciliation** was already achieved where traceability databases were in place, but blockchain support now ensures information cannot be changed once entered without leaving a track of those changes.
- **Perceived strengthening** of chain of custody and strong market interest

CHALLENGES

- **Value added, and mixed products** challenge volume reconciliation and traceability
- **Smallholders** produce large shares of certain commodities (seafood, cocoa, palm oil, coffee) and their effective integration may be challenging by technical literacy and infrastructure
- **Training and adoption** of a new technology and getting people to feel comfortable with data entry
- **Veracity** of collected data and reliability of related process are key problems that require the involvement of a third party through audits and inspections

In one of the first available use cases driven by a certification scheme the Best Aquaculture Practices (BAP) certification scheme announced testing a blockchain-traceability application for traceability and mass balance at supply chain level in June 2018 (BAP, 2018). The application described in Table 4-2 is intended to be accessible to actors with different levels of digital literacy and infrastructure to ensure access for the large smallholder share among aquaculture farms. First experiences have shown that the technical solution was unproblematic from a software development perspective and that successful deployment mostly depends on user engagement and training to ensure good data quality.

Table 4-2 - Use case 1: Best Aquaculture Practices

Type	Certification scheme developing blockchain traceability application
Objective	Provide a credible traceability solution to businesses that must comply with traceability regulations and meet consumer expectations
Involved parties	GAA BAP (certification scheme); Kuai Shrimp (Shrimp farming company)
Status	Pilot announced in 2018
Description	• Traceability application ultimately aimed to be open to all certified companies • Intended as a voluntary supplement to a certification scheme with existing traceability standards • Functions as supply chain level volume reconciliation tool • Uses the public Ethereum blockchain • Blockchain receives information on origin and type of product (species, product form), as well as destination. • Focus on accessibility to smaller operations (farms) • All actors are anonymised, only the scheme owner has the means to reveal their identity when needed
Challenges	• Ensuring batch level traceability beyond the processing plant when supply is dominated by small and medium sized farms • Integration of data collection into work processes and habits
Conclusions	• Technical aspects unproblematic • Engagement and training (at farm level) are key to ensure participation and good quality data entry

4.1.2 Traceability

The lacking connectedness of chain of custody audits and the reliance on paper-based documentation were also identified as slowing down and increasing cost of tracebacks. The Program Director for Scandinavia and the Baltics of the Marine Stewardship Council highlighted how resource-intense tracebacks are becoming a challenge for certification schemes that are using on product labels.

"When it comes to food and food systems there is that kind of almost 'human right way' that you need to show where it comes from"

Increasingly aware consumers are seen to expect that traceability and origin information are just a click away in a digitalised world, while this is not how certification schemes were initially conceived. Interviewees reported that the resource-intensity of tracebacks under current conditions has led their number to stagnate while the number of certified operations grows.

Reported challenges are dependent on the level of traceability that is aimed for. Section 3.1 introduces different types, among which identity preservation is considered the most stringent. It usually involves that a product can be traced to a specific place of production. The often promoted blockchain-enabled farm-to-fork traceability applications (Carrefour, 2018) may however only go as far as being able to attribute a product to a group of dozens if not hundreds of farmers. Certain products, like shrimp, are often grown by small-scale producers that only deliver small batches of non-homogenous products that need to be mixed and sorted according to size at the processing facility. As several interviewees reported, this continues to make farm-level traceability for individual batches economically unviable, but blockchain-supported applications can help to record and identify which farms' products went into what batch. Establishing a stable link between a physical product and its digital representation was generally highlighted as key challenge for lower value and processed goods.

Companies that already had fully running traceability databases did not report any operational or traceability quality changes. Instead they emphasized increased trust and market interest in their product and related information.

Table 4-3 - Findings for BCT impact on traceability

EXPECTED

- **Reducing complexity** of traceability in value adding supply chains by creating digital tokens that represent the physical good, following it along the supply chain and being reduced similarly to the physical product each time it undergoes transformation resulting in product loss.
- **Traceability speed** will increase as all relevant information is available online in a connected string allowing even immediate tracebacks

DEMONSTRATED

- **Blockchain-traceable** delivery from small and large-scale producers was achieved
- **Operations and traceability quality** (speed, granularity) did not change where traceability databases were already in service prior to blockchain introduction

CHALLENGES

- **Physical digital connection** remains problematic for low-value and bulk goods, especially as the latter ones are often mixed and hard to be traced individually, leaving product substitution as a persistent problem, in particular for processed products
- **Identity preservation** and remains a challenge unrelated from blockchain technology. Even where farm level traceability is desired this might not be economically feasible as batches may be mixed and sorted at processing facilities according to different quality criteria. Where feasible it might require organisational changes.
- **Censorship resistance** of blockchain-secured information is a central argument for the technology's advantages but was questioned in cases where errors had to be corrected

In 2017 the World Wildlife Fund for Nature New Zealand, blockchain technology provider Viant, traceability technology company TraSeable and Fijian tuna fishing company SeaQuest teamed up to pilot a blockchain-supported traceability system for MSC certified longline caught yellowfin tuna (see Table 4-4). The project coordinator stated that:

> *"It's about creating a transparent and traceable supply chain that would allow us in markets to leverage influence and ultimately direct behaviour of producers at the waterline level. […] we think it's an overall benefit to the industry to be engaged in blockchain traceability and it will certainly be a very strong tool to use to encourage sustainability in the fisheries that are participating in the supply chain tool."*

The project aimed at creating a completely transparent and traceable supply chain and was able to provide a proof of concept by delivering a shipment of blockchain traceable tuna.

Table 4-4 - Use case 2: Longline Tuna Fishery in Fiji

Objective	Create a completely transparent and traceable supply chain through a traceability database combined with a blockchain application
Driven by	Consortium consisting of WWF New Zealand (NGO), Viant (blockchain technology provider), TraSeable (traceability technology provider), SeaQuest (fishing company)
Status	First pilot phase focusing on proof of concept completed in 2018
Description	• Ethereum blockchain-based application Viant was used to explore the inclusion of all supply chain actors with adaptable applications, allowing reflection of individual business processes, smart contract building and tracking • Successful digital tracing of fish from an MSC certified fishery within the Fijian domestic market and of a single delivery to the US • Reusable RFID tags were deployed to mark and capture data from each fish individually, QR coded packages were used to trace cuts from individual fish
Challenges	• Lacking digitalisation of supply chains as key challenge for any traceability solution • Local availability of expertise for technical support systems (i.e. to deploy technical infrastructure required to bridge physical and digital) • Knowing and engaging the full supply chain • Ensuring data quality • Transaction speed of the used blockchain • Uncertainty over cost
Conclusions	• Critical to differentiate between data points in a given supply chain that are stored on/off the blockchain • Appropriate incentives for data capture are essential • Real-time volume reconciliation will make fraud and erroneous entries easily visible

Source: Based on the 2018 WWF Briefing "Blockchain: Transforming the Seafood Supply Chain" (Cook, 2018) and interview with project lead

4.2 Auditing

First, the analytical framework assumed that a BCT based application would support the auditor with easy access to records, potentially highlight risk areas and help to focus audits. While interviews showed that to be the case where no elaborate traceability database was in use before, not such changes were reported where a blockchain application was only built on top of an existing system.

Second, the analytical framework supposed that a BCT based application could facilitate the creation of micro-claims that are comparable between certification schemes, potentially reducing audit scope and cost for operations audited against different certification schemes with overlapping criteria. While this hope was expressed by some projects (RSB et al., 2018)., interviewees raised doubts on whether this would actually be possible given the different stakeholder-driven standard setting processes that would have to be aligned.

Third, it was assumed that BCT driven transparency and immutability of once entered information could make certain (CoC) audits redundant as trusted information can be verified remotely. This expectation was echoed by several interviewees for blockchain and non-blockchain-based applications. However, a reduction of CoC audits in practice was not yet reported.

4.2.1 Efficiency

Several interviewees expected the number of chain of custody audits in low-risk areas to decrease as these would be easier to identify with certitude in a data-driven approach. Expectations varied with regards to the overall number of audits from elimination of chain of custody audits to no change as human interaction would always be required to verify that processes are being followed in reality. No changes were reported and expected where blockchain-supported traceability systems are already in place.

Table 4-5 - Findings for BCT impact on audit efficiency

EXPECTED

- **Reduced need for CoC onsite audits** and may even eliminate need for CoC audits for those parties that do not transform or only deal with product in tamper-proof form
- **Reduced audit scope**, especially for CoC audits, as certain data points can be verified automatically and would not be possible to tamper without noticing
- **Cross scheme audit result exchange** and resulting limited scope of later audits could be enabled by sharing results on overlapping already verified criteria of different schemes

DEMONSTRATED

- **Efficiency gains for chain of custody audits** were reported but linked to deployed traceability data base that was already available before blockchain deployment. Efficiency gains were related to speeding up audits by spending less time on collating information
- **Audit scope and intensity** were not seen or expected to change where blockchain-supported traceability systems are used as third-party verifications of actual procedures and input data quality are still considered essential

CHALLENGES

- **Harmonisation of standards and audit procedures** was considered a key challenge that would need to be addressed before effective exchange of audit results and recognition of micro claims across different certification schemes could be achieved through a blockchain-supported application
- **Flexibility of applications** towards accepting non-programmed data points was questioned, while flexibility was considered an important criterion to strengthen effectiveness of audits by allowing auditors to review and report suspicious observations that are possibly outside of an audit protocol but contradict the intent of an audited standard

In 2017-2018 the certification scheme owner Roundtable on Sustainable Biomaterials, blockchain service provider Provenance, timber products company UPM and the certification scheme membership organization ISEAL Alliance conducted a blockchain pilot study along a certified sustainable biomass value chain. The pilot described in Table 4-6 focused on a feasibility study and identification of possible benefits from introducing a blockchain-based application across different schemes along UPM's supply chain. While this case does not involve a food commodity supply chain it was thought to be relevant as it represents one of the first application cases of blockchain technology that also involved a certification scheme owner.

Table 4-6 - Use case 3: RSB certification blockchain pilot

Type	Pilot study
Objective	Create understanding for technology and investigate advantages of deploying blockchain-based traceability in certified supply chains
Involved parties	Roundtable on Sustainable Biomaterials (certification scheme), Provenance (blockchain service provider), UPM (producer of biomass and other timber products), ISEAL Alliance (membership organisation for certification schemes)
Status	Completed pilot study, conducted in 2017/18
Description	• Analysed sustainable biomass supply chain certified against three different certification schemes the criteria of which strongly overlap • Found that audit records are not shared across certification bodies, resulting in duplication of audits • A joint database would significantly reduce time required to familiarise with new facilities and to collect data • Possibility to automatize and strengthen greenhouse gas reporting by connecting all involved nodes through a blockchain using smart contracts to automatically generate emission values based on input
Challenges	• Blockchain and related technologies are still nascent, large scale deployment will take time, research and investment
Conclusions	• Suggest a public blockchain to develop a collaborative database across certification bodies • Suggest creation of micro-claims attached to each standard criterion to allow use across different schemes in same supply chain

Source: Based on the summary report of the joint blockchain pilot by RSB, ISEAL, and Provenance (2018)

4.2.2 Effectiveness

Audit effectiveness can be described as well functioning assurance through (third-party) auditing that processes and other standard criteria are being followed as required by the certification scheme owner. While several interviewees expect blockchain-supported certification processes to result in more effective audits, no evidence for actual effects could be provided. This is again due to the very early status of blockchain development along certified supply chains. However, increased effectiveness is expected from the greater data availability and full chain visibility once a possibly blockchain-supported solution is deployed.

Table 4-7 - Findings on BCT impact on audit effectiveness

EXPECTED
• **Risk focused auditing approach** will be further strengthened through greater data availability and support focussing audits on the weak points of a supply chain • **Immediate record availability** may help to focus time spent at client facility on audit • **Continuous verification** will increase effectiveness, especially through combination with other IoT technologies • **Improved monitoring** and ability for targeted follow up will increase effectiveness
DEMONSTRATED – None reported in interviews, remains to be seen
CHALLENGES – None reported in interviews, remains to be seen

4.3 Trusted information

The analytical framework assumed that blockchain's inherent quasi immutability strengthens trust in supply chain information and certification claims. Nearly all interviewees confirmed this assumption, stressing that the key impact of blockchain technology will be strengthened trust in information provided through certification or other production and supply chain related processes. The chief data officer of the French certification body Bureau Veritas added that:

> *"The key thing that blockchain is changing is establishing a way of sharing efficiently in a trusted way, everybody can say, I understand, and I can see these rules, and everyone follows the same, I can share and have the same control as everyone in the system, that's what blockchain changes."*

Others added that reduced trust in organisations or entire industries creates entry points for blockchain-based solutions. Both interviewees that were and were not directly involved in blockchain pilots highlighted the fact that using blockchain for supply chain information would also avoid the challenge of handing over data to one central actor. The previously cited Bureau Veritas employee also stated:

> *"Anything that you can do on the blockchain you can do it on a centralized database. What we recognize is that there is no one, including ourselves who is completely legitimate to host such a centralized database, no one wants that responsibility because we are not legitimate to track everything. That is where the blockchain comes in. The idea is that each party will share data with control over confidentiality and the key data for traceability, not all the data, only the key data for traceability will be shared nested with all participants of the supply chain. That way we solve the question of the legitimacy of who owns data because everyone holds data"*

The strong reliability of blockchain-secured information was also highlighted as an important marketing factor that was already seen to reflect on brand reputation and the credibility of certification claims. In this context one interviewee highlighted the increasing digitalisation of supply chains as a challenge as certain systems risk to be comparatively easy to manipulate without leaving traces. Blockchain-secured supply chain information would not be exposed to the same risks in his view.

Table 4-8 - BCT impact on trust in information

EXPECTED

- **Providing trusted information the integrity of which is not questioned is the key reason for any supply chain or certification project to use blockchain technology**
- **Distributed data storage is perceived to circumvent the challenge of handing over information to one central and possibly vulnerable authority, which is seen as a particular advantage with sensitive supply chain information**
- **Importance of certification schemes and independent auditing is expected to increase in the foreseeable future as deployed systems will not be able to detect all types of fraud or mistakes and require verification to avoid perpetuation of false information**
- **Certification and blockchain-supported applications are seen as complimentary solutions for the delivery of sustainable and traceable products**

DEMONSTRATED

- **Blockchain-supported traceability systems have seen market interest as pioneers launched first certified product lines supported by blockchain-based applications**

CHALLENGES

- **Ensuring high data quality, especially at the first step of data entry, is seen as a crucial element for successful deployment of any blockchain-based solution.**

The next example is provided by Pacifical, a tuna marketing company that was set up by the parties to the Nauru Agreement: the Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, and Tuvalu. Their waters are home to 25% of the global tuna stocks, including a fishery that produces 50% of the global skipjack tuna catch. The 2011 MSC certified company already operated a fully digital and online accessible traceability system that allowed consumers to track individual tuna cans back to processors and the boat that initially harvested the fish.

To strengthen the credibility of their certification-related claims Pacifical contracted a blockchain service provider to secure selected data fields from its traceability database on the Ethereum blockchain. Since August 2018 customers and consumers can also look up the production-transactions through the Ethereum browser Etherscan (see Appendix E). The provided information is limited to selected chain of custody related data fields like vessel names, species and harvest date. Pacifical did not report any changes in what or how information was recorded and shared. But the availability of tamper-proof data through a publicly available ledger is expected to strengthen the credibility of claims on product packages and to support differentiation from self-declarations of other brands.

Table 4-9 - Use case 4: Pacifical's blockchain-supported traceability system

Type	Company's own traceability system partially on blockchain
Objective	Strengthened trust in provided information and market differentiation
Involved parties	Pacifical (tuna marketing company), Atato (blockchain service provider)
Status	Operational since August 2018
Description	• Pacifical operated a traceability database for several years that was also used to ensure and demonstrate compliance with the MSC chain of custody standard • A web application already provided batch traceability for customers and consumers based on can codes • Selected data fields (i.e. vessel, captain, catch trip dates, species etc.) from the existing traceability database are now saved on the Ethereum blockchain • No operational changes were required and the certification process as such was not affected • Reported cost were not significant due to existing database infrastructure
Challenges	None reported
Conclusions	• Pacifical's blockchain-supported traceability received widespread media attention and created marketing value • Facilitates fraud detection, as producers being able to detect fraudulent claims made by traders related to their product (in one case an importer was falsely claiming to sell Pacifical product, which could be proven wrong thanks to database, also not necessarily impacted by blockchain deployment) (Brownjohn, 2018)

Source: Interview with company representative and company documents (Pacifical, 2018)

4.4 Effects on certification bodies

The second part of the analytical framework focuses on the implications of blockchain technology introduction for certification bodies. Three key areas were addressed during the interviews: activities and responsibilities, skills, and business opportunities.

The analytical framework assumed blockchain supported solutions in supply chain networks to require activities like access management and authorization of at least the writing parties to certify their capability and reliability to supply accurate data. Depending on the set of possibly newly required activities the framework also assumed that CBs might have to acquire new skills to audit a participant's IT infrastructure and data management processes. Finally, the framework supposed that the introduction of this technology may bring new business opportunities.

In general interviewees agreed that the importance of in-person audits at production sites and along the supply chain will not decrease in the foreseeable future. Those piloting blockchain-based applications recognised that fraudulent actors would always find a possibility to introduce false information and that certain errors or deceptive actions will not necessarily be registered as such by an application.

4.4.1 Activities

There are strongly differing views of what the future role of certification bodies will be when it comes to supply chain auditing. In general, those working directly in or with certification do not see the role of certification bodies to change drastically in the short term. The specific expertise that they bring to a company for their repeated short-term deployments through audits was mentioned to be too expensive to internalize and was seen as unlikely to be replaced by blockchain applications as onsite presence was considered essential. Even when combined with sensor technology as seen in many pharmaceutical supply chains, interviewees stated that there is still a need for auditors to verify proper installation and functioning of the deployed devices. Those actors that have a greater focus on the technology itself see a reduced need for chain of custody auditing but recognise that onsite presence will not be fully obsolete.

Table 4-10 - BCT impact on certification body activities and responsibilities

EXPECTED

- **On site production audits** are generally not expected to decrease in importance even with the deployment of additional technology (i.e. internet-connected sensors) as specific standards (i.e. working conditions) cannot be verified remotely
- **Data management and analysis** is expected to become significantly more important for CBs as the increasing deployment of sensors will result in more than just traceability data and CBs may have access to large data streams across companies
- **Data veracity and integrity verification** are expected to become a significant part of a CB's work

DEMONSTRATED

- **CBs will have a gatekeeper role**, depending on who is administering the system (private blockchain), where they provide access to supply chain actors and validate their identities
- **Importance of chain of custody audits** as such is not considered to decrease based on first applications, but they might be more targeted and certain actors might not be audited at all depending on their product handling. Even for automated volume reconciliation an onsite audit might still be required where for example product conversion factors do not match and might need to be verified and adjusted for individual companies.

CHALLENGES

- **Data management and analyst role may require new skill (see next section)**

4.4.2 Skills

Interviewees did not agree on how required certification body skills will change. Some considered it to be the application developer's responsibility to ensure that auditors could use blockchain-based application just as any other IT tool they are currently using without developing deeper understanding for the technology itself. Others, including actors involved in the deployment of blockchain-based applications, considered it important for the CB to develop skills that would allow auditing the client's IT interface. The different views may also result from different expectations about how any given application would be designed in terms of functionalities and who would be deploying it. No further IT skills are expected from CBs for solutions that are fully provided by scheme owners and operate independently from specific client IT systems.

Table 4-11 - BCT impact on required certification body skills

EXPECTED

- **Develop skills to audit client IT systems,** which seems particularly relevant when the CB itself deploys a blockchain application and needs to ensure flawless communication with client systems
- **Data management and analysis skills** may become more relevant as blockchain application deployment is likely to go in parallel to fitting supply chains with internet-connected sensors, potentially giving CBs access to large amounts of data

DEMONSTRATED – None reported in interviews, remains to be seen

CHALLENGES – Not relevant as skills development as such is a challenge

4.4.3 Business Opportunities

The deployment of blockchain-based applications is driven by a variety of different organisations, including retailers (Carrefour, 2018), technology companies (CGF & IBM, 2017) and certification bodies (Bureau Veritas, 2018). While current applications are mostly limited to pilot test scales, the engagement of leading companies like IBM, Walmart and Carrefour suggests a level of confidence in this technology that promises a market demand for new applications. Interviewees highlighted the offering of new traceability applications, for example in the form of traceability labels, and data analysis services as new business opportunities.

Table 4-12 - BCT impacts on business opportunities

EXPECTED

- **New data analysis-based services** may be offered to existing clients as CBs gain access to significant amounts of data across clients that could provide new insights, i.e. to improve production processes

DEMONSTRATED

- **New traceability applications** such as labels and online lookups have been proposed by various certification bodies as new services to brands and retailers to create added value by enhancing shopping experiences and increasing consumer trust

CHALLENGES - None reported

In 2018, Bureau Veritas announced the traceability label origin that would allow consumers to find out about a product’s history by scanning a QR code that allows to access product-related information from a blockchain-supported database (see Table 4-13).

Table 4-13 - Use case 5: Bureau Veritas Origin label

Use case 3	**Bureau Veritas - Origin**
Type	Blockchain supported traceability application and label
Objective	• Value creation through farm-to-fork traceability • Cost reduction through targeted recalls • Enhanced value chain control
Involved parties	Burau Veritas (certification body), Worldline (platform provider for secure digital transactions)
Status	Pilot, launch expected early 2019
Description	• Traceability application and on-pack label based on private blockchain solution • Provides proof to supply chain partners that agreed rules and quality requirements were adhered to • Aimed to be built on top of existing traceability databases or function as standalone solution for traceability related information • Currently trialled in the fisheries sector • No direct connection to certification

Source: Based on interview with company representative and Bureau Veritas (2018)

4.5 Other

The interviews and reviewed use cases revealed several relevant topics outside of the applied analytical framework. A few findings, like cost implications, digitalisation and privacy, are briefly reported as they seem critical when evaluating impacts and benefits of blockchain technology for certified supply chains.

Digitalisation of supply chains in general was a frequently mentioned cause for effects like improved traceability that many often associate with blockchain technology (Tripoli & Schmidhuber, 2018). It was highlighted that blockchain technology in current supply chain applications does not offer more functions than other cloud-based solutions. The main highlighted advantage is increased trust in the reliability of the provided information. Overall, interviewees agreed that the food sector in general is lagging when it comes to digitalisation. The continued strong reliance on paper-based systems was repeatedly identified as one barrier to improved traceability. This could be addressed by the push for blockchain solutions, noting that the main benefits, like increased supply chain visibility, are not directly related to blockchain technology itself, but associated to the required digitalisation.

Cost was another common theme. Those less involved in blockchain projects expect the technology to drive down cost. Retailers like Walmart echo this expectation, if solutions are implemented at larger scale and if cost calculations also involve the possibility to reduce the impacts from food crises by allowing more targeted recalls (Yiannas, 2018). If these effects are not considered, the developers of blockchain-based applications do not expect them to drive down supply chain control cost compared to current levels. However, they expect a net positive through increased product value. WWF New Zealand’s tuna project is one of the very few examples that published an overview of the cost incurred by fitting a supply chain with the hardware and software to enable blockchain-supported traceability (Cook, 2018a, p. 27). However, the cost for the actual blockchain platform was not provided. This is due to the fact that the early stages and rapid development of the technology make it very difficult to precisely estimate the cost (Cook, 2018a, p. 26). It should be noted that the fishing operation under question apparently had to introduce the complete infrastructure required to enable digital traceability, which was responsible for a large share of the overall cots. Costs incurred from linking existing infrastructure and functioning traceability databases were reported to be negligible, as in the case of interviewed tuna marketing company Pacifical. This is in line with what other interviewees reported who attributed a significant cost share of any such project to the establishing of a traceability data base, regardless of the technology used as well as the fitting of supply chains with sensor and tracking technology.

Privacy was another frequently mentioned concern. While in general an increasing pressure on companies to share data was reported, several interviewees doubted that the spirit of public verifiability as propagated by most blockchain projects suits the reality of confidential business relationships. The resistance to data sharing was also highlighted as a challenge encountered by the previously referenced WWF New Zealand project:

> *"One difficulty that we've already experienced is trying to get participants on board and in the export process. People just don't want to give up that information. Information is power. Information is influence and control and if you are exposing yourself, particularly in the seafood industry to the fact that the only value that you're providing is handing it from your right hand to the left hand. Then you know, your business model is at risk."*

The providers of private blockchain-based applications recognized this challenge stating that the identity of supply chain actors is private information and should remain so. They highlighted their role in this context to manage participation and set rules for identity revelation. One interviewee highlighted the importance of such private blockchain solutions being deployed by independent actors to avoid a further downstream powershift in supply chains.

5 Discussion

Three core assumptions were made at the outset of this study. First, sustainability certification continues to be an important tool in value chain management and helps various actors to achieve their business and sustainability objectives. Second, certification processes suffer from insufficient information-sharing and verification practices that can result in supply chain integrity risks, inefficiencies and damaged trust. And third, blockchain technology can help address these issues by enabling real-time sharing of immutable and therefore trusted information.

Section 4 provided an interview and use case-based account of experiences and expectations on how selected aspects and actors in sustainability certification will be affected by the introduction of BCT. This section discusses the main findings in accordance with the two research questions and underlying hypotheses and relates them to the current academic debate. Sections 5.1-5.3 will discuss the meaning of findings for answering research question 1 with three focal aspects: chain of custody, auditing and trust.

RQ(1) **How is blockchain technology impacting (sustainability) certification processes?**

Section 5.4 then goes on to discuss the reported and expected impacts on certification bodies, as per research question 2, focussing on activities, skills and business opportunities.

RQ(2) **How will blockchain technology impact the operations of certification bodies?**

5.1 Chain of Custody

The initial supposition presented in the analytical framework was that a blockchain solution would strengthen the chain of custody in three ways:

1. Ensuring that sold volumes of certified material match produced volumes through automated volume reconciliation.
2. Preventing substitution of certified with non-certified products.
3. Enabling a more granular traceability level and product tracking.

There is little doubt that chain of custody certification and supply chain traceability in general will see the most immediate benefits from BCT-based applications. The findings seem to indicate that applications that have been deployed or are being developed will at least ensure (1) immediate volume reconciliation at supply chain level and counter (2) product substitution through improved traceability. Little can be concluded about the achieved level of traceability (3) as this seems to depend more on organisational changes along the supply chain than on the underlying database technology itself. This could for example mean changing from a segregation to an identity preservation traceability system. The discussion below will therefore not address hypothesis (3) and instead focus on hypotheses (1) and (2) presented in the chain of custody section of the analytical framework. It will also provide a broader view of what blockchain technology might bring to chain of custody certification. Hypothesis 1 from the CoC section of the analytical framework states that:

H(1) Blockchain improves CoC integrity through shared distributed records and continuous data capture that enable immediate traceability and volume reconciliation at each step by connecting audits and traceability events across supply chain actors.

According to interviewees from retailers and certifiers it is not uncommon for buyers to rely on certification schemes as only traceability system for those products covered by the respective scheme. The current approach to chain of custody certification may however hide certain risks in the supply chain that only manifest at second or third tier supplier level. As repeatedly highlighted, such chain of custody risks may be difficult to detect for auditors because of disconnect between audits along the supply chain.

The main challenge encountered when trying to assess the effects of BCT is that much is still based on expectations as actual applications have either just been launched; trialled in a very restricted setting that does hardly allow any conclusions about constellations involving less motivated actors; or did not involve the deployment of an actual application as some pilots were restricted to establishing potential benefits of a supply chain moving to a blockchain-supported approach (RSB et al., 2018).

This challenge is also reflected by much of the existing literature that is characterised by discussions of potential improvements while lacking insight into actually deployed solutions and achieved benefits (Galvez, Mejuto, & Simal-Gandara, 2018; Lu & Xu, 2017; Sander, Semeijn, & Mahr, 2018).

Volume reconciliation is an important objective of blockchain-based applications as proposed by the Best Aquaculture Practices certification. Many of the widely used certification schemes for sustainable food commodities are still lacking digital systems to easily verify that quantities sold under their label conform to certified production quantities. They rely on supply chain actors demanding the correct documentation from their suppliers, on separately conducted supply chain audits to ensure custody integrity, as well as sporadic manual traceback and volume reconciliation exercises for selected supply chains. Interviewees provided examples of how this approach makes it difficult to systematically detect erroneous and fraudulent statements about traded quantities and to prevent product substitution in a supply chain, especially in situations where volume records are consistent. This seems to support hypothesis (2):

H(2) The deployment of blockchain-based traceability systems will make the substitution of certified by non-certified products immediately detectable.

One interviewee reported that such product substitution could happen when a supplier works with both certified and non-certified materials and orders for either do not align with available product, providing incentives to sell certified as non-certified and vice-versa to satisfy orders.

Such actions are notoriously difficult to detect under current systems but could be made more difficult when a delivery is connected to an immutable production history and digital representation that was confirmed by all network participants on a system that does not allow double-spending of the same product identity. Blockchain-based solutions as proposed by Provenance (2016) would enable exactly that.

However, accidental or intentional product substitution in situations with parallel handling of certified and non-certified lots is likely to remain a challenge. It seems that especially for hard to tag bulk goods a strict management process for product handling is indispensable and should be at the focus of ensuring product segregation and identity. This may also come back to requiring the deployment of sensors to for example capture storage room opening times and pass that data on for comparison with other control points to enable triangulation for data consistency verification.

The expectations associated with blockchain technology in supply chains are to improve traceability in general and more specifically for certification to strengthen the chain of custody while decreasing the related audit burden. Some of the applications reviewed in this study, like Bureau Veritas' Origin or WWF New Zealand's pilot, are intended to be integrated with and connected to existing client databases along the supply chain, thereby creating a continued digital flow of information. In addition, these solutions, as the one presented by Pacifical and Atato, aim to increase trust in the provided information through blockchain's censorship resistance.

None of the projects mentioned until now have gone so far as to directly integrate features of reducing the manual labour burden in chain of custody auditing, through for example more extensive use of sensor monitoring of product flows. A blockchain-based traceability application was however recognised to bear the potential of eliminating certain chain of custody auditing activities, depending on the level of automation and sensor fitting of certain processes as well as real-time tracking and volume reconciliation at supply chain level. The actual benefit depends however on the design of the related standard as some already do not require auditing of actors that only handle tamper-proof packaged goods, like canned food.

The actually achieved effect on certification schemes, in particular chain of custody certification, is likely to depend on several factors:

5.1.1 Who introduces blockchain and with what objectives?

Like with any software solution the scope and functionalities are decided on by the parties that are deploying and using it. What may seem obvious is less trivial when considering how parallel or integrated functioning of certification schemes and blockchain-based traceability solutions would work. Currently tested applications that were presented in this study are focusing on limited steps along a supply chain. They were tailored to one company's system, and had not been designed for interoperability with specific certification standards.

Sander et al. (2018, p. 2075) conducted a study on the potential acceptance of a blockchain-based traceability system for meat. They recognised that any system would need to be holistic and introduced at sufficient scale to deliver the expected benefits in terms of traceability and supply chain integrity. Reducing the need for chain of custody audits under any third-party sustainability certification scheme would require that (1) the architecture of an application accommodates the requirements set by a scheme's standard and (2) that the standard or scheme owner recognises the possibility to demonstrate compliance through an application in line with his requirements. From a scheme owner's perspective, it seems to make most sense to provide their own solution as this would (1) enable easy integration with standards set by that scheme; (2) most likely ensure accessibility to certified small- and large-scale operations; and (3) would increase scheme integrity by enabling better control of certified product flows and label use.

While this approach would strengthen trust in a certification scheme's claims, it would certainly be challenged by some large operators. The Marine Stewardship Council currently pilots a digital traceability program named Project Product Provenance (MSC, 2017). The exact scope and functions of this non-blockchain-based database project are not yet known, however, the consultations also resulted in pushback from actors who felt this would duplicate their existing efforts (MSC, 2016). Similar efforts by the Forest Stewardship Council, a certification scheme for sustainable forestry, have failed. The 2014 launched Open Claims Platform was supposed to function as a database for certification status of suppliers and as a traceability database that would enable product tracking. Many companies refused to participate on the grounds of duplicative efforts and unwillingness to provide one organisation with that much valuable supply chain information. Depending on its design, a blockchain-enabled platform could resolve this issue as data would not be centrally stored at one organisation but remain distributed over the network of certified organisations. The properties of BCT could potentially convince organisations to open up to data sharing. However, as recognised by interviewees involved in different blockchain traceability projects, creating the willingness to share data seems to remain a key challenge to any such application. The downside to a scheme-driven solution would be its likely limitation to products within one certification scheme's scope. This might be challenging for processors and producers of mixed products that are handling many different types of certified products. Given the currently limited interoperability of different blockchains they could find themselves in a situation requiring them to adapt to multiple systems, which is usually not associated with increased efficiency.

An alternative approach could be development and deployment by certification bodies as they often operate across many commodities and therefore benefit from understanding the particularities of different sectors. However, the currently developed solutions are aimed at providing traceability labels for brands and retail and not at facilitating greater efficiencies by integrating with chain of custody certification. RSB et al. (2018) provide an interesting proposition where certification bodies would operate on a common blockchain network to exchange claims that could both enable increased supply chain integrity as well as greater auditing efficiency as discussed in section 5.1.2.

5.1.2 Finding consensus

Consensus is a crucial term in blockchain lingua since it describes one of the core mechanisms making blockchain platforms through immutable provenance records so relevant for supply chain management. But another consensus appears to be required to fully reap the benefits of applying this technology for traceability. One interviewee described the current development of blockchain-based traceability applications as a global arms race. This is worrying as it might leave the food sector with a similarly challenging situation that it is already facing: a number of different systems and standards that limit effective information exchange across supply chain networks (Bhatt et al., 2016, 2017). Waiting for one solution to outgrow the competition would be one option but probably not the best as businesses may risk losing competitive advantage. As one interviewee pointed out a better option seems to be closely monitoring efforts towards interoperability of different blockchains. Projects like Aion (Aion Foundation, n.d.), Cosmos (Kwon & Buchman, n.d.), or Polkadot (Wood, 2016) are developing new protocols that aim for interoperability of applications run on different networks that may be public, private or a combination of both. These developments might have the potential to create what Bhatt et al. (2016, p. 392) described as "a global, secure, interoperable support system for […] food traceability". The effective functioning of such a system would however also require that actors align on key data elements that need to be registered.

Digital tracing and tracking are possible under many other systems as well. Statements by blockchain application providers that blockchain-based traceability systems do not provide more functions than other available systems per se might leave some questioning the benefits of this technology. However, the perspective of an interoperable system with tamper-proof product histories and instant traceability or even trackability should encourage further piloting.

5.2 Audits

The analytical framework assumed that blockchain-based applications could improve audit effectiveness and efficiency in four ways that will be discussed hereafter.

> *H(3) Blockchain-based systems provide better access and trusted information before and during audits that and help to drive a risk-focused audit approach.*

The expectations towards blockchain-supported and other digital audit databases are significant as reported in section 4.2.1. Experiences, in particular with blockchain technology-supported traceability systems and their impact on auditing processes, are however limited. In this study, only one firm could be interviewed that had already launched an online traceability database and secured selected traceability relevant information via blockchain. This obviously limits the possibility to draw generalisable conclusions. The firm did not report any changes in terms of how audit samples were selected or how it affected the efficiency of audits as such. In this particular case it should be acknowledged that their use of blockchain technology also did not aim at impacting these aspects since the key focus was providing customers with additional assurance about the validity of their claims. Major benefits, such as immediately available information that reduce auditing effort were ascribed to the already installed online traceability system. Likewise, the strengthening of risk-based auditing approaches would be linked to the fact of having a real-time updated database in place, whether that is making use of blockchain technology or not.

> *H(4) Blockchain-based systems could enable the creation of micro-claims that reflect audit results for individual certification scheme requirements. This in turn would enable a modular auditing approach that reduces duplication of audits for companies working with different certification schemes and buyers.*

The International Trade Centre's latest review of market adoption of sustainability certification indeed highlights the multiple certification of producers (Lernoud et al., 2017, p. xiii). While not focusing on sustainable food commodity production, Schwarzkopf, Adam & Wittenberg highlight duplication of certification and related audits as a key challenge in supply chain management that could possibly be addressed by blockchain-based traceability application (2018, pp. 172–173).

One solution that could be offered by such an approach is a shared audit database with modularised audit results. This database could be accessed for subsequent audits to avoid verifying the same criterion twice at an organization audited against two different standards (RSB et al., 2018, p. 7; Schwarzkopf et al., 2018, p. 177). Standards interoperability is a topic that has occupied the wider sustainability certification community for a long time with programs trying to decrease auditing duplication through combining audit checklists (Global G.A.P., 2015) or merging altogether (Rainforest Alliance, 2017a). While the interviews revealed interest in blockchain applications further enabling such interoperability to decrease audit burden, challenges with that approach dominated discussions. One example is rooted in standards development. The type of standards discussed in this thesis are usually the result of extensive stakeholder dialogue, producing different standards or sometimes only different ways in which standards ask for certain requirements to be fulfilled. Interviewees highlighted this as a particular challenge for any interoperability or harmonisation approach required for enhanced efficiency. Once more, the problem appears to be less tied to technical feasibility of a shared blockchain-based application than making different organisations agree on common approaches and data sharing.

H(5) The blockchain-enhanced transparency and immutability of once entered information could make certain on-site (CoC) audits of low-risk clients redundant as trusted information can be verified remotely.

Komives & Jackson (2014, p. 10) discuss various ways in which digital and online tools could help certification schemes to advance traceability and audit efficiency, even replacing certain audits. These expectations were shared by some of the interviewed representatives of certification scheme owners and certification bodies, especially for low-risk actors that do not process or otherwise change the certified product they are handling. However, the question remains whether this is an issue that should be resolved through sensor-driven remote audits or through adapting the applied traceability standards. Programs like the MSC and ASC for example explicitly exempt actors that only handle tamper-proof packaged goods from the requirement to undergo chain of custody certification (MSC, 2015). For a blockchain-based application to change the need for on-site audits, one can safely assume that it would require first a review of applied standards to determine possibly superfluous audits and secondly adapt standards to accommodate the possibility of reducing the need for certain audits based on the applied technology.

5.3 Trust

The third section of the analytical framework proposes that:

H(6) The censorship resistance inherent to blockchain technology, combined with unique digital product identities and the possibility to track and trace strengthens trust in claims.

Strengthening trust in supply chain relationships and product -claims is a core argument supporting many blockchain for supply chain projects (Ge et al., 2017, p. 10). According to Fowler (2018, p. 905) it is a “modern reality that certifying corporate social responsibility involves many different types of entities with varying levels of accountability” and thus varying levels of trust that actors are willing to place in these entities. Such entities include certified supply chain actors as well as certification schemes. By providing a full and immutable account of a product’s lifespan, blockchain-based systems would address the trust issue inherent in most supply chain relationships, which is also supported by Kshetri (2018, p. 86).

As expected, most interviewees highlighted increased trust in product histories and related claims as the main reason for introducing blockchain-based applications along supply chains. In addition, blockchain’s distributed data storage with no central party owning or managing that data was highlighted. It is an important argument in favour of using the technology in supply chain networks that are wary of power disbalances that would be created by centralised information storage.

However, evaluating the real effects on customer, let alone consumer, will require observations over a longer timeframe. This was currently not possible due to the very recent market introduction of blockchain-based traceability applications.

5.4 Effects on Certification Bodies

At first glance, the existence of certification bodies and other third-party verifiers seems to be contradicting a central claim of initial blockchain projects: enabling secure trade without requiring a trusted third party (Nakamoto, 2008). However, those initial considerations were focusing on the transfer of digital property titles, like electronic cash, for the purchase of goods and services without having to represent particular properties of the service or good in question. In this situation a seller is protected by the irreversibility of cryptographically secured payments and buyers would be insured through regular escrow mechanisms (Nakamoto, 2008, p. 1). The challenge is different in a supply chain relationship that requires certification of certain practices and actors. Here, the trading parties are often separated by multiple intermediate actors that may change a product's attributes while it travels along a supply chain. These changes are of physical nature and need to be verified at each step where they happen and conformity with defined standards needs to be assessed, securely stored and communicated. As long as developments in artificial intelligence and sensor technology do not offer cost-competitive and fully trusted alternatives, there needs to be third-party intervention when verifying product and process attributes.

This links in with an issue that was consistently discussed in interviews: Data quality probably remains the most significant challenge for a blockchain-based system to deliver additional value for certification schemes and traceability. While a blockchain-based system ensures data integrity in the sense that information cannot be changed once put into the system, it cannot ensure on its own that this information was correctly entered in the first place.

Data quality is a multi-faceted issue that challenges how certification bodies operate while at the same time making the case for certification bodies in a blockchain-supported network. As one interviewee put it, data quality requires that auditors, and everyone else involved in data collection, have a common understanding of why and how certain data should be collected and will be used by downstream actors and processes. Recent efforts by the Forest Stewardship Council and Accreditation Services International point out how this may be a challenge even across auditors within one certification scheme. FSC auditors commonly used different templates during audits, which made monitoring of certification processes and outcomes difficult. The two organisations therefore got together to develop a digital cloud-based tool to support harmonisation of data collection and to improve quality of collected data (ISEAL, 2018).

Interviewees highlighted that, even where supply chains were already fully fitted with sensor technology, intervention by certification bodies was required to verify proper functioning of those devices as well as process steps that could not be fully captured by sensors. The old problem of "garbage in, garbage out" remains and seems to become even more relevant in a blockchain-supported system, as once entered information becomes immutable.

The need for a blockchain gatekeeper bears the potential to strengthen the position of certification bodies, depending on how they adapt to potential new roles and responsibilities. These will be discussed by reviewing the results presented in section 4.4 against the three hypotheses addressing impacts on certification bodes. Hypothesis 7 supposed that:

H(7) *Blockchains in a supply chain network will result in new activities for certification bodies.*

In the short to mid-term, interviewees did not see a decreased importance of certification bodies and their on-site presence. However, a few responses indicated that this required presence could be drastically reduced in the longer-run with the advent of more reliable remote auditing infrastructure. Given that many sustainability standards cover a mix of relatively complex environmental and social criteria with varying margins of discretion for compliance assessment, a decrease of on-site audits is hard to imagine. Criteria that aim at preventing threats, harassment and improving other aspects of human wellbeing[7] usually require in-person discussions with the workforce. Thus, they are unlikely to be replaced by digital systems[8].

Views on the future of on-site chain of custody auditing varied significantly. A minority of interviewees sees them being replaced through blockchain-supported systems. However, the majority expects that they would remain relevant but that blockchain technology driven data collection will result in redeployment of efforts to risk areas and will see certain checks being automated. Mass balance exercises could be one example. Besides these certification process-specific issues, the probably more urgent challenges are related to the question of who deploys a blockchain network in a supply chain and with what scope and purpose. None of the observed projects seem to currently consider moving an entire chain of custody system to a blockchain network. Currently piloted applications appear to come in addition to a traditional chain of custody certification. However, should chain of custody certification be integrated into a blockchain system, a number of learnings from the interviews appear to be relevant. As previously discussed, certification bodies could be the entities that introduce such a system. In that case they would indeed be required to act as an IT provider that introduces and integrates a blockchain system with client systems. In addition, it will also require the certification body to act as gatekeeper that grants supply chain actors with access to a system. This will however require verifying that an actor's local systems and processes and the proposed blockchain system can be integrated. Interviewees disagreed whether this responsibility falls to the certification body of another IT company that originally developed the blockchain system at question. It is likely that the overall impact also depends on the size of a certification body. While large operators are already proposing new blockchain-based applications, smaller actors are likely to be unable to integrate these specialized capabilities and might need to consider partnering with larger actors. Hypothesis 8 supposed that:

H(8) Blockchains in a supply chain network will require new skills from certification bodies.

As discussed under hypothesis 2.1, depending on who introduces a blockchain-based system the CB might be required to develop skills to audit client IT systems to ensure that they communicate accurately with any deployed system. This was also raised as an issue during several interviews and a key finding of a pilot study the University of Wageningen conducted in collaboration with producers, importers, certification bodies and other actors along an organic table grape supply chain (Ge et al., 2017, p. 26). A more precise account of skills cannot be provided here as this would have required detailed access to a use case focusing on this specific issue.

However, the broader standards community is actively looking into developing standards for blockchain and distributed ledger technologies. In 2016, the International Organization for Standardization created Technical Committee 307 to drive standardisation of blockchain technologies and distributed ledger technologies (ISO, n.d.). While the initial focus lies on the technology itself, the committee is also liaising with ISO's chain of custody committee. This is a space that should be closely monitored as it could result in new standards relevant to

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[7] See for example the Rainforest Alliance's Sustainable Agriculture Standard's section on critical criteria for improved livelihoods and human wellbeing (Rainforest Alliance, 2017b, p. 45)

[8] This is not to say that digital systems do not play an important supporting role here. See for example efforts made by seafood company Thai Union to improve surveillance and fishing crew communication possibilities (McBain, 2017)

certification bodies operating in blockchain-supported supply chain networks. Hypothesis 9 supposed that:

H(9) Blockchains in a supply chain network will offer new business opportunities for certification bodies.

Various certification bodies have responded with new service offerings to the strong interest in blockchain technology. Especially large companies like Bureau Veritas (Bureau Veritas, 2018) and Det Norske Veritas (Vestvik-Lunde, 2018) have started to compete with new blockchain-based traceability labels that enable consumers to discover the story behind a product by for example scanning a printed QR code. The very recent launch of these projects makes it difficult to assess whether this is indeed a viable business opportunity. But considering the strong interest of retail frontrunners like Carrefour (Carrefour, 2018) and Walmart (Nash, 2018) and their investments in blockchain traceability applications for high-value food products, there appears to be a market in the making for those actors that have sufficient resources for such product and service development.

Another business opportunity mentioned by an interviewee was not blockchain-specific but related to the access to potentially significant data flows. Depending on the progress of sensor technology deployment and access granted to the collected information, certification bodies could build up significant metadata from different production processes that other divisions of the certifier could use for consulting services. This would however require very careful evaluation to avoid violating standards that accredited certification bodies need to follow themselves. Impartiality requirements defined in ISO 17021:2015 could be interpreted as preventing such services since they may increase financial dependence of a certifier to a level that threatens its independence when auditing and certifying (ISO, 2015).

5.5 Reflections

The application of blockchain technology in supply chains, and in particular in the context of sustainability certification, is a very recent phenomenon. Academic interest as measured by results for the search term 'blockchain' is soaring. 84% of all 930[9] articles listed on Web of Science were published in 2017 and 2018, with the first articles being listed in 2013. The focus on supply chains is even younger. 95% of the only 45 'supply chain' results were published between 2017-2018. While sustainability of supply chains is peripherally mentioned (Kshetri, 2018), no studies have as of yet established the impact of blockchain technology on certification as a core instrument in sustainable supply chain management. The few available studies that create a link between certification and blockchain are currently limited to assumptions of potential impact (Düdder & Ross, 2017; Fowler, 2018; Schwarzkopf et al., 2018). Outside of academic journals, a couple of relevant use cases and pilots were published (Cook, 2018; Ge et al., 2017).

5.5.1 Analytical approach

The poorly researched relationship between certification and blockchain technology thus warranted a comparatively broad approach when conducting this study. This particular area of research is still underdeveloped and relevant issues and questions where yet to be established. This thesis attempts to fill parts of that research gap by addressing a relatively large number of aspects of certification that are likely to be affected by blockchain technology. It should be recognised that the breadth of this approach limits the detail in which certain relationships could be explored and explained. This might in turn limit the usefulness of findings to certain

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[9] Status as of 19 September 2018 for all publications available on www.webofsciecne.com, with first publications in 2013.

actors. It should however be recognised that despite choosing a relatively broad approach, this thesis does not represent a full account of impacts as areas including impact monitoring and feedback to standard setting process have not been considered.

This thesis departed from a very practically oriented perspective, i.e. trying to further the understanding of how processes and actors will be impacted by a new technology. It therefore focused on practical functions and challenges of certification and blockchain technology instead of developing a broader theoretical framework. Given that several interviewees stressed the importance of training and acceptance, in hindsight a different point of depart could have been chosen. Davis (1989) technology acceptance model could have provided a useful framework to review specific barriers and drivers for blockchain technology uptake within certification processes. An alternative approach could have been offered by Schoemaker's scenario planning (1995). This tool is particularly valuable when "try[ing] to capture the new states that will develop after major shocks or deviations in key variables" (Schoemaker, 1995, p. 25), a generic description that fits many blockchain predictions. However, the ten-step planning process would have required focusing on impacts on a particular actor, given the limited time available for this project.

5.5.2 Interviews

Interviewee selection and availability should also be kept in mind when understanding the findings of this project. A very diverse set of experts was interviewed, driven by the ambition to provide a holistic view of expected impacts of blockchain technology on sustainability certification. While it did result in a good overview of many expected impacts, the reliability of findings could have been strengthened by either increasing the sample size (20 experts were interviewed) or focusing on representatives of fewer stakeholder groups to enable within group comparisons of responses. Availability of certain expert groups represents a further limitation to the presented findings. Blockchain experts from service providers that actually develop blockchain applications were not available despite multiple requests. Their insights could have provided new perspectives on information exchange challenges along certified supply chains and the actual potential of blockchain applications to provide an improvement. A significant number of blockchain project whitepapers and case studies was reviewed to counterbalance this deficit.

Interviews lasted between 35 minutes and close to two hours. Many interviews revealed additional relevant topics and questions, some of which were integrated into subsequent interviews. Reliability of findings could have been improved by choosing a different overall setup of the interview process that would have been more appropriate to this new research field where many pertinent issues remain to be uncovered. Instead of conducting interviews in a single continuous string, a two-tiered approach could have resulted in more telling insights. This is what the delphi method aims for: focusing on knowledge rather than data generation (Verschuren, Doorewaard, & Mellion, 2010, p. 223). Findings from the first interview are reviewed and discussed a second time with the same interviewee to ensure that they see all relevant issues being covered. While this approach seems very appropriate for this young area of research, it would not have been feasible within the given amount of time. A final noteworthy limitation is linked to the chosen case study research design. It allowed to discover a broad array of issues While these issues appear relevant to many actors possibly affected by BCT, generalisability is limited to due to a comparatively small set of interviewees and reviewed use cases. Organisations wishing to use the results of this study should keep those limitations in mind and are advised to take them as a starting point for their own work and not as firm advice.

6 Conclusions

Food scandals and exposure of unsustainable production practices have called the integrity of the food sector into question. Certification has been an important part of businesses responding to those challenges. But even this approach has been confronted with cases of fraud that threaten its credibility. Blockchain has appeared as a potential technological solution and it is hard to overstate current expectations. Various UN agencies and the recently installed UN Secretary General's High-level Panel on Digital Cooperation (UN, 2018) have made blockchain technology a priority when assessing disruptive digital innovations. The latest report by the World Economic Forum and PricewaterhouseCoopers calls blockchain-enabled 'see-through' supply chains a game changer for addressing issues in natural resource and food trade (World Economic Forum, 2018, p. 14). Following the same line of thought, UN FAO considers the technology to hold significant potential for food value chains by improving transparency, traceability and trust among trading partners (FAO, 2018, p. 180; Tripoli & Schmidhuber, 2018). These objectives seem familiar when compared to what many food sustainability certification schemes set out to achieve through standards and credible assurance mechanisms. Blockchain as a decentralized immutable source of provenance information is expected to provide supply chain assurance with new powerful tools, also strengthening certification.

Just as the technology and its implementation in supply chain management, the related academic work is very much in its infancy. This thesis is intended to (1) provide a contribution to further define the field of research on blockchain applications for supply chain management and certification, and to (2) share practical insights into how key actors and instruments may be affected by conducting a series of expert interview and reviewing use cases. Two research questions were asked and answered as follows:

RQ(1) How is blockchain technology impacting (sustainability) certification processes?

Bearing in mind the limitations discussed in section 5.5, it was shown that blockchain technology has the potential to strengthen supply chain and certification scheme integrity through immediate volume reconciliation. Its ability to provide the backbone for powerful traceability infrastructures, enabling immediate access to relevant traceability events was confirmed. Chain of custody certification processes stand to benefit the most from an immutable digital support structure as provided by blockchain technology. Increasing overall audit efficiency and effectiveness seems also a likely outcome where blockchain applications are built to support certification processes and supply chain assurance. However, this remains to be seen as more experience is being gathered with such applications. Strengthening trust in brands and products was also seen as a key reason to engage in blockchain projects. This appears to be an important lesson for certification schemes that consider different alternatives to build up digital traceability infrastructures under their labels. The censorship resistance of blockchain-secured information seems to have created a high level of trust by different market actors in systems applying BCT. Very much in line with this conclusion, WWF New Zealand's Western Pacific Tuna Program Manager stated that

> "*blockchain, along with third party certification is the best way forward […]. [I]t will create inherent trust in the supply chain and it will create a lot more transparency that'll help us exclude illegal and unethical products from the supply chain, um, that we previously haven't had available with the existing traceability structures.*"

RQ(2) How will blockchain technology impact the operations of certification bodies?

Certification bodies are key actors in the realm of independent third-party sustainability certification. Initial concerns that the certification industry might become obsolete could not be confirmed. Nevertheless, some drastic changes can be expected in the mid to long-term perspective. The effects on certification bodies are likely to vary massively between different value chains and are dependent on who introduces a blockchain-based application and with what purpose as that will affect the scope of current and additional activities.

While overall there was no clear indication for diminished need of certification body services, it became clear that activities might shift in a blockchain scenario. This could include reducing the need for certain chain of custody audits, driving risk-based approaches, as well as new tasks in blockchain-supported systems where the certification body could be required to act as gatekeeper and administrator. This in turn seems to require new skills to be able to integrate solutions with client systems and audit data collection infrastructure. The advent of blockchain technology also offers new business opportunities for certification bodies. This was shown by different actors who started launching new traceability services, including traceability systems and consumer facing labels that enable farm-to-fork provenance documentation.

The food industry's current situation and how blockchain fits in

Food production systems are at the frontline when it comes to tackling global environmental and social issues ranging from disrupted global nutrient cycles, climate change, biodiversity loss to modern day slavery. Reliable information on who produced a product where and under which condition is a critical enabler for meaningful solutions. Third party certification remains a widely used tool to identify products derived from socially and environmentally more sustainable processes. Critics state that their impact in the current form is limited, at best (Froese & Proelss, 2012; Grassroots & EIA, 2015; Jacquet et al., 2010). Standard implementation and information-sharing practices resulted in doubt whether certification schemes can live up to their promise of more sustainable products. More efficient sharing of trustworthy information is a key condition to strengthen trust in certification schemes, their positive impact, and the food system in general. Global food production systems are still perceived as lagging behind compared to other industries when it comes to process digitalization, including supply chain information-sharing.

The debate on the opportunities of blockchain technology may help propel the industry to a modern state, along with a host of other relevant technologies, such as digital sensors, and artificial intelligence making sense of big data streams. The possibility to share tamper-proof records along supply chains is a significant benefit of blockchain technology, but several challenges remain to be solved that include: ensuring first step data quality to avoid the garbage in, garbage out problem; making the technology easily accessible to smallholders and ensuring it does not result in fencing them out of the market; and avoiding misuse that could give false credibility to claims based on false information.

An important lesson from this study seems to be that it is not blockchain alone that will do the job of solving the aforementioned problems. Many of the advantages associated with blockchain technology, such as traceability and trackability of products, are not related to the technology as such but to increased digitalisation of supply chains. While a powerful instrument, blockchain technology should not be considered the silver bullet to all integrity issues within food supply chains. As WWF New Zealand's Western Pacific Tuna Program Manager stated:

> *"Blockchain is not going to eliminate the possibility of fraud or malfeasance in the supply chain, but what it will do is make it infinitely more detectable. I think that's one of the primary roles that blockchain is going to play."*

Another important factor for future impacts of blockchain-supported traceability solutions on certified supply chains will be whether they come as a mandatory requirement or a voluntary add-on. At this point, certification schemes seem to be hesitant to even think about mandating the use of a traceability databases they provide, and certified companies seem to raise legitimate concerns about data security and duplication with their own systems. However, examples of voluntary efforts with hardly any uptake, like the Forest Stewardship Council's Open Claims Platform for certified timber, might make compulsory participation an option that some actors want to consider, if they want to strengthen the overall integrity of their programs.

Does it have to be blockchain?

As previously stated, a number of actors along certified supply chain still doubt whether new traceability systems need to be blockchain-based for their purposes. Well established certification schemes like the Marine Stewardship Council focus their effort on piloting cloud-based solutions that are not including blockchain platforms. The early status of many blockchain applications and risks related to security, interoperability and technological maturity (World Economic Forum, 2018, p. 22) seem to detract some organisations from wholeheartedly embracing blockchain.

Blockchain technology is developing rapidly with new applications or even new blockchain ecosystems being launched at a breath-taking pace. This also involves important improvements of existing blockchains. The significant energy consumption and transactional inefficiency of public blockchains that use proof-of-work consensus mechanisms have been criticised repeatedly. Many applications that aim at advancing environmental sustainability (Provenance, Responsible Timber Exchange) are run on Ethereum. While more efficient protocols are expected soon, Ethereum's current energy consumption equals that of over 1,8 million US households (Digiconomist, 2018). The trade-off between blockchain's benefits for supply chains and the significant energy consumption seems hardly justifiable for sustainability-oriented applications. Until improved protocols have been released for public blockchains like Ethereum, it appears that the more efficient private solutions are preferable, at the expense of public verifiability and transparency.

Suggestions for Future Research

This case study revealed a number of research areas and questions that could inspire further projects to understand the impact and added value of blockchain technology for supply chain management and sustainability certification. These include:

Does it make sense for supply chain applications? Practitioners and scholars should remain critical when answering this question and might want to remember an early claim made in the blockchain debate: "the main benefits are lost if a trusted third party is still required to prevent double-spending" (Nakamoto, 2008, p. 1). Blockchain applications should be carefully compared to non-blockchain-based solutions. The added value of having a system blockchain run must be clearly visible

Comparative performance assessment of blockchain and non-blockchain driven traceability applications used by certification schemes should be developed. Comparative case studies of operational applications should be conducted to understand the impacts of both types on variables such as supply chain integrity and user trust in related claims.

Research should produce more case studies on running projects. The findings of this paper are limited in their explanatory power by the fact that current developments in blockchain applications for supply chain management and for certification are dominated by proof of concepts, pilot projects and incomplete supply chain coverage where applications have been fully launched. The real impacts and potential benefits can only be evaluated once applications have been in use for a sufficiently long time.

Evaluating which organisations (i.e. certification bodies, certification schemes, retailers, etc.) should drive deployment of blockchain applications, including traceability systems, would help to understand how to achieve the broadest or most meaningful impact for a given purpose. While retailers might prioritize full chain traceability for high value goods, certification scheme owners would probably be more interested in ensuring integrity of all supply chains certified under their scheme, regardless of product value, to strengthen trust in their label and claims. This should also include an evaluation of which organisation would be best placed to govern non-public blockchains used for supply chain traceability.

Blockchain traceability systems that reward initial data collectors with digital tokens represent innovative incentive mechanisms for high-quality traceability data in otherwise challenging situations (i.e. remote small-scale fisheries). The effects of these approaches, as proposed for example by Fishcoin (2018), should be compared to conventional non-blockchain-based traceability applications, as offered by projects such as Ababalobi (2018).

Researching the necessary skills to work along blockchain-supported supply chains would help certification bodies to develop the necessary skills and clients working along those supply chains to select adequate service providers.

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Appendix

Appendix A – List of Interviewees

Organisation	Representative	Title	Duration (h)	Format
Accreditation Services International	Richard Vout	IT Solutions Architect	1:35	Online
Axfoundation	Hanna Skoog	Project Manager	0:45	In person
Bureau Veritas	Michel-Ange Camhi	Chief Data Officer	1:00	In person
The Consumer Goods Forum	Ruediger Hagedorn	End-to-End Value Chain Director	0:35	Online
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	Viktor Peter	Blockchain Governance Expert	0:57	Phone
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	Philipp Schukat	Former Programme Director Social and Environmental Standards	0:50	Online
Fintegration	Katryna Žukauskaite	Consultant	0:50	Online
Global Aquaculture Alliance	Andy Raynor	IT Manager	0:55	Online
Inter IKEA Group	Charlotte Huus-Henriksen	Global Food Sustainability Developer	1:15	Online
Inter IKEA Group	Christoph Mathiesen	Sustainability Advisor	0:20	Online
International Pole and Line Foundation	Alice Miller	Social Research and Programme Director	0:37	Online
ISEAL Alliance	Ana Garzon	Manager Innovations	00:55	Online
Marine Stewardship Council	Minna Epps	Program Director Scandinavia and Baltic Sea Region	1:00	In person
Marine Stewardship Council	Mark Luckins	Director of IT	1:06	Online
Metro AG	Britta Gallus	Director, SCM, Programs & Risk Assessment	0:55	Online
Metronom	Oliver Teschl	IT Manager, Traceability	0:55	Online
NEPCON	Roman Polyachenko	Traceability Program Manager	1:16	Online
Pacifical	Maurice Brownjohn	Commercial Director	1:12	Online
Swedish National Agency for Public Procurement	Helena Robling	Sustainability Specialist	0:50	Online
World Wildlife Fund for Nature New Zealand	Bubba Cook	Western Central Pacific Tuna Prorgamme Manager	1:00	Online

Appendix B – Sample Interview Guide

Interview guides were adapted several times during the interview process as new topics came up in earlier interviews that needed to be addressed in the outstanding interviews. The example below represents the final version that covers all questions that were discussed.

1. What are common challenges that you observe in certified supply chains with regards to traceability and data integrity? Do they differ across the commodity supply chains you are working with?
2. What are the key challenges in currently deployed certification processes or other assurance models where blockchain-based applications could provide added value?
3. How would blockchain technology help to address the challenges you identified?
4. Do you see any advantages of using blockchain-based solutions instead of more "traditional" centralized data base applications within the context of supply chain management (and sustainability certification)?
5. What are the primary challenges when implementing electronic database-supported traceability and assurance instruments in (food) supply chain certification?
6. Are you expecting blockchain-based solutions to change how supply chain assurance providers like certification bodies are working?
7. Are you expecting the certification body's (required) service portfolio to change?
8. Are additional skills and capacities required from assurance providers (like certification bodies) that operate along a blockchain-supported certified supply chain?
9. How/will blockchain-based applications change how verification of harvesting, production, processing and other chain of custody related data is being conducted?
10. Are you expecting blockchain-based solutions to change how certification schemes and various certification bodies are collaborating among each other?
11. Will the accreditation body's role change, should certification processes start using blockchain?

Appendix C – Codebook version (I)

Code book version (I) was developed based on the analytical framework and represents a near verbatim translation of the suppositions. Version (I) was produced before the transcribed interviews were read and coded.

Name
1. Chain of custody
1.1 Traceability
1.2 Trackability

Name
1.3 Integrity
1.4 Physical-digital connection
1.5 Prevent certificate double-spending
1.6 Volume reconciliation
2. Audit
2.1 Audit effectiveness
2.2 Audit efficiency
2.2.1 Duplication
2.2.1.1 Handlers
3. Trust in Certification
4. Effects on CBs
4.1Activities & responsibilities
4.2 Skills
4.3 Business opportunities

Appendix D – Codebook version (II)

Version (II) of the code book builds on version (I) and was developed after a first read of all transcripts. This version represents the final coding structure and was used to code all interviews. Changes compared to version (I) are highlighted in red. It should be noted that the focus remained on parent codes 1-4. Parent codes 5-16 represent topics that were deemed relevant within the broader discussion on the potential impact of blockchain technology on certification, traceability and supply chain assurance. Not all of these discovered topics are addressed in the thesis, but the codes were reported to report the complete coding process.

Name
1 Chain of custody
1.1 Traceability
1.1.1 Speed
1.1.2 Traceability challenges
1.1.3 Examples
1.1.4 Beginning vs. End of chain
1.2 Trackability
1.3 Integrity
1.4 Physical-digital connection
1.5 Prevent double-spending
1.6 Volume reconciliation
2 Audit
2.1 Audit effectiveness
2.1.1 Coverage
2.1.2 Risk focus
2.2 Audit efficiency
2.2.1 Duplication
2.2.1.1 Handlers

Name
3 Trust in Certification
3.1 Trust in scheme
3.2 Trust in third party
4 Effects on CBs
4.1 CB Activities & responsibilities
4.2 CB Skills
4.3 CB Business opportunities
5 Blockchain Vs. Centralized
5.1 Blockchain advantages
5.2 Blockchain challenges
5.3 Centralised advantages
5.4 Centralised disadvantages
6 Company Size
7 Cost
8 Customer expectations
9 Data ownership
10 Digitalisation
11 Human factor
12 Marketing
13 Privacy
14 Security
15 Supply chain effects
15. 1 Middlemen
16 Fraud

Appendix E – Pacifical's Blockchain Lookup

(1) Pacifical's Blockchain Lookup on the publicly accessible part of their website

Blockchain Lookup

Want to try it out? Use this tracking code to see how it works: U73X2CBNN3NMBN
Interested in using our blockchain viewer for your business? Click here to find out more.

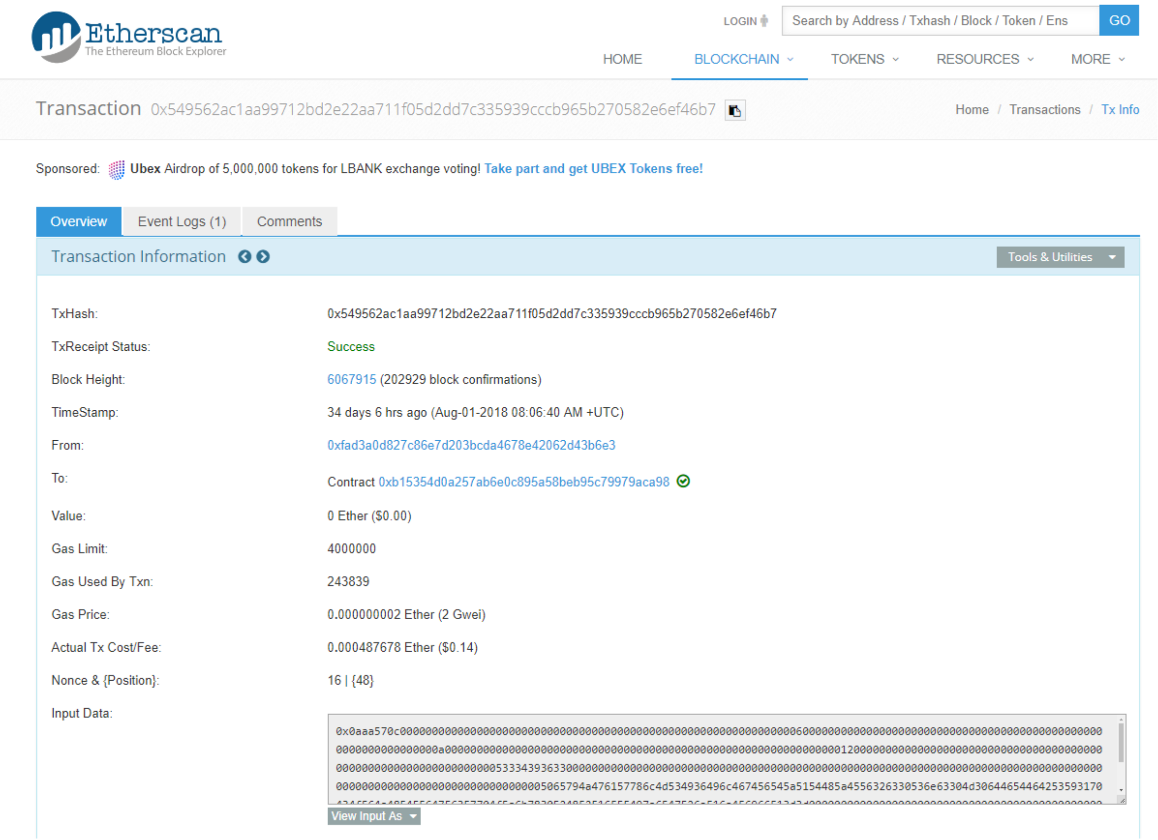
U73X2CBNN3NMBN

Blockchain Transaction: 0x549562ac1aa99712bd2e22aa711f05d2dd7c335939cccb965b270582e6ef46b7
Blockchain Timestamp: 1/8/2018

Blockchain Data:

```
                                     {
  "MscTripNo": "M12005-12004-06-020-2S",
  "CatchingPeriodStart": "2017-07-18T00:00:00Z",
  "CatchingPeriodEnd": "2017-08-14T00:00:00Z",
  "CaptainName": "Chang Wen Wu",
  "FishingVesselName": "Jih Yu 768",
  "CarrierVesselName": "Katah",
  "DischargeDateEnd": "2017-09-30T00:00:00Z",
  "CatchingArea": "PNA Waters FAO 71-77",
  "Processor": "SV Unicord",
  "ProductionCodes": [
    {
      "ProductionCode": "U73X2CBNN3NMBN",
      "OuterUnits": "2394",
      "Species": "MSC Skipjack Tuna",
      "PackingStyle": "solid pack",
      "PackagingMedium": "brine",
      "NetWeight": "200.000",
      "DrainedWeight": "155.000",
      "MeasurementUnit": "g",
      "PackagingForm": "Canned",
      "ProductionDate": "2018-02-22T00:00:00Z",
      "BestBeforeDate": "2021-02-22T00:00:00Z",
      "Brand": "Raimond Freres"
    },
    {
      "ProductionCode": "U73X2COSN3TMBN",
      "OuterUnits": "2793",
      "Species": "MSC Skipjack Tuna",
      "PackingStyle": "solid pack",
      "PackagingMedium": "oil-sunflower",
      "NetWeight": "200.000",
      "DrainedWeight": "155.000",
      "MeasurementUnit": "g",
      "PackagingForm": "Canned",
      "ProductionDate": "2018-02-22T00:00:00Z",
      "BestBeforeDate": "2021-02-22T00:00:00Z",
      "Brand": "Raimond Freres"
    }
  ]
}
```

(2) Related information on Ethereum's browser Etherscan where transaction histories can be viewed.



Transaction 0x549562ac1aa99712bd2e22aa711f05d2dd7c335939cccb965b270582e6ef46b7

Sponsored: **Ubex** Airdrop of 5,000,000 tokens for LBANK exchange voting! **Take part and get UBEX Tokens free!**

Transaction Information

TxHash:	0x549562ac1aa99712bd2e22aa711f05d2dd7c335939cccb965b270582e6ef46b7
TxReceipt Status:	Success
Block Height:	6067915 (202929 block confirmations)
TimeStamp:	34 days 6 hrs ago (Aug-01-2018 08:06:40 AM +UTC)
From:	0xfad3a0d827c86e7d203bcda4678e42062d43b6e3
To:	Contract 0xb15354d0a257ab6e0c895a58beb95c79979aca98 ✓
Value:	0 Ether ($0.00)
Gas Limit:	4000000
Gas Used By Txn:	243839
Gas Price:	0.000000002 Ether (2 Gwei)
Actual Tx Cost/Fee:	0.000487678 Ether ($0.14)
Nonce & {Position}:	16 | {48}

Input Data:

```
0x0aaa570c000000000000000000000000000000000000000000000000000000000000006000000000000000000000000000000000000000000000000
000000000000000a0000000000000000000000000000000000000000000000000000000000000120000000000000000000000000000000000000000
00000000000000000000000533343936330000000000000000000000000000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000005065794a476157786c4d534936496c467456545a5154485a4556326330536e63304d30644654464253593170
```