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TOWARDS A CIRCULAR ECONOMY:

INTEGRATING BLOCKCHAIN TECHNOLOGY INTO SUPPLY CHAIN MANAGEMENT

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"As people alive today, we must consider future generations: a clean environment is a human right like any other. It is therefore part of our responsibility toward others to ensure that the world we pass on is as healthy, if not healthier, than we found it." (Lama, 1990). [1]

Dalai Lama

[1] Lama, D. (1990). Universal Responsibility and the Good Heart. In *Freedom in Exile: The autobiography of His Holiness the Dalai Lama of Tibet* (pp. 280-299). Hodder and Stoughton.

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List of Abbreviations

AI	Artificial Intelligence
B2B	Business-to-business
B2C	Business-to-consumer
DLT	Distributed ledger technology
GDP	Gross Domestic Product
GPS	Global positioning system
IOT	Internet of Things

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Preface

Before you lies the thesis "Towards a Circular Economy: Integrating Blockchain Technology into Supply Chain Management". The thesis is written to meet the graduation requirements of the BSc. Global Responsibility and Leadership at the University of Groningen | Campus Fryslân. The research and writing for this thesis spanned the course of eight months. Together with my supervisor, Prof. dr. Andrej Zwitter, the research question of this thesis has been formulated, which I have been able to answer through extensive research. This study would not have been possible without the contributions of many professionals who were willing to share with me their knowledge on the topics of this thesis without hesitation.

I would first like to express my sincere thanks to Prof. dr. Zwitter for his exceptional guidance and support throughout the Capstone Project. Over the past eight months, I have come to know Prof. dr. Zwitter as the most inspiring, open-minded, and intellectual professor and dean of the Campus Fryslân faculty I have encountered during my academic and professional career. At all times, he was willing to offer support, and his efforts have contributed enormously to ensuring the scientific validity and accuracy of this thesis. Second, I would like to thank all respondents to this study for their time and effort in giving me insight into their vision on blockchain technology, supply chain management, and the circular economy. Their expertise and experience were crucial in analyzing the integration of blockchain technology in supply chain management to advance the development of the circular economy. Third, I would like to thank my family members and friends for their support and motivation during this research.

With that, I look back on an outstanding academic experience in which I finished my BSc. Global Responsibility and Leadership and completed the minor Governance and Law at the University of Groningen. It has been a fantastic adventure in which I have made great friends, met remarkable people, and became familiar with sustainability issues within the economic and political domain. Although I will never stop learning, I would like to sincerely thank the many teachers and fellow students who have contributed to my academic experience.

I hope you enjoy your reading.

Roel van Klaveren

Abstract

Purpose
This study aims to bridge the research gap on the adoption possibilities of blockchain technology in supply chain management that can promote circular economy practices.

Design/methodology/approach
Using an abductive research approach, qualitative semi-structured interviews were conducted with representatives and experts from organizations, companies, and government agencies who had adequate knowledge of blockchain-based supply chain management systems that could promote circular economy practices.

Findings
The findings show that blockchain technology can contribute to supply chain management in various ways to promote the circular economy. However, the findings suggest that the first step for supply chain stakeholders is to get better at the data of their business processes so that their decision-making process can be better organized. Only then does it become relevant to consider whether blockchain technology can add value to supply chain management to achieve a defined objective.

Originality/value
This study is one of the first attempts to examine the integration of blockchain technology in supply chain management to promote a circular economy.

Keywords: blockchain technology, supply chain management, circular economy, Industry 4.0, digitalization, smart contracts, reverse logistics.

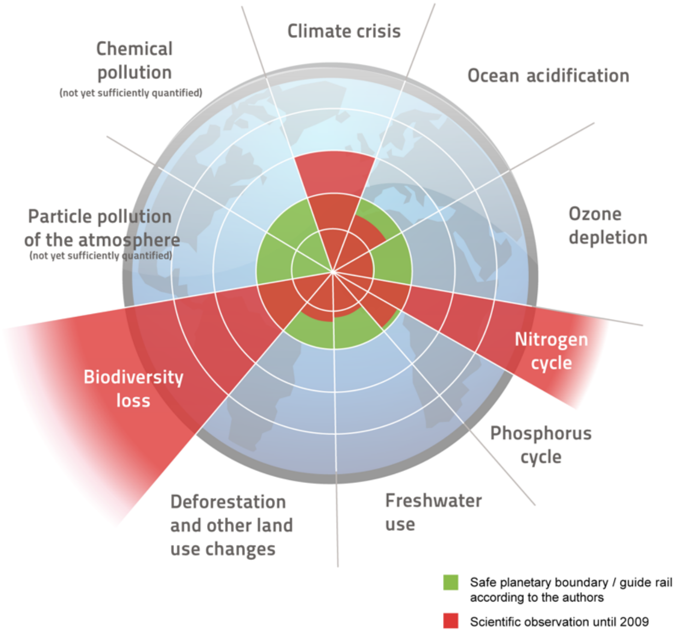
1. Introduction

Industry 4.0, also known as the "Fourth Industrial Revolution", is seen as a complete transformation of our society: an amalgamation of the physical, digital and biological worlds (Upadhyay et al., 2021). According to Luthra et al. (2019), Industry 4.0 focuses on strengthening industrial capabilities through the intensification of technological applications and digitization. The integration of artificial intelligence (AI), robotics, the Internet of Things (IoT) and other Industry 4.0 technologies is changing the way we produce and offers opportunities to change our lives. On the other hand, this transformation also highlights the need to consider creating a more environmentally sustainable society. According to a report by McKinsey & Company (2016), most environmental impacts could occur within consumer goods supply chains. As industrial activities are a significant driver of environmental degradation and resource depletion, the concept of a circular economy has evolved over the past decade to address these global issues (Geissdoerfer et al., 2017; Wang et al., 2020). The circular economy offers opportunities for sustainable development due to its ability to reduce waste, close material and energy cycles, and change business models (Geissdoerfer et al., 2017; Kirchherr et al., 2017). However, to realistically implement the circular economy, systems with basic competencies such as traceability, transparency, and provability are needed (Yildizbasi, 2021). These basic competencies have also become critical requirements in globalized supply chains. With the advent of Industry 4.0, modern supply chains have become highly complex systems where production and distribution processes are geographically dispersed worldwide. This complexity makes it challenging to conduct efficient transactions, trace materials and products, and assess data from supply chain processes (Ivanov et al., 2018). The capabilities of blockchain technology can support building supply chains with solid features of traceability, transparency, trust and stakeholder collaboration while addressing environmental, financial, and social sustainability issues. The integration of blockchain technology into supply chain management to promote the circular economy is a topic that connects two megatrends: digitization and sustainability. The connection of these two megatrends creates the challenge of designing and using technologies for a sustainability transformation of the linear economic paradigm (Böckel et al., 2021).

1.1 Environmental relevance

The prevailing linear economic model in the Global North is based on a linear approach, suggesting an unfinished process where the factory supplies the processed materials and collects the waste after using the products. While this economic system has generated significant growth in GDP and human well-being, it has simultaneously caused significant damage to the natural world (Böckel et al., 2021). As shown in *Figure 1*, humanity is currently in an ecological deficit due to resource exploitation and life beyond planetary boundaries (Rockström et al., 2009). These ecological issues have emphasized the need to consider alternative economic models, such as the circular economy. In contrast to linear economic models, the circular economy offers new opportunities for sustainable development through its ability to reduce waste and reuse, recycle and recover materials in the production, distribution, and consumption process. According to the circular economy principle, raw materials should remain in operation for as long as possible and be recycled at the end of their life (Yildizbasi, 2021). The need to ensure sustainable economic growth and production and consumption patterns is also recognized in the United Nations Sustainable Development Goals. Therefore, this study is particularly aligned with Objective 8.2, which aims to "achieve higher levels of economic productivity through diversification, technological modernization and innovation", and Objective 12.5, which aims to "significantly reduce waste generation through prevention, reduction, recycling and reuse" (UN, 2022).

Figure 1 *Planetary Boundaries (adapted from Rockström et al., 2009)*



1.2 Research focus

This study was conducted to provide a clear insight into the possibilities and opportunities of blockchain technology in supply chain management to promote the circular economy. While the use of blockchain technology is still in its infancy, understanding the early developments and existing knowledge gaps related to the integration of blockchain technology into supply chain management for a circular economy is essential. The central aim of this study is to bridge the research gap on the adoption possibilities of blockchain technology in supply chain management that can promote circular economy practices.

The central aim is broken down into several objectives. The first objective is to describe the primary qualifications of blockchain technology. Consequently, the adoption possibilities of blockchain technology in supply chain management will be clarified. The second objective is to identify common challenges that supply chain management currently faces. This sheds more light on the reasons why blockchain technology can add value to supply chain management. The third objective is to describe practices and strategies to promote the transition to a circular economy.

1.3 Research question

The systematic review by Yli-Huumo et al. (2016) has revealed that less than 20 percent of all blockchain-related research concerns the potential adoption of blockchain technology. While some studies have been conducted on the potential of blockchain technology for supply chain management, a comprehensive investigation into the integration of blockchain technology in supply chain management to promote the circular economy is a recognized research gap (Wang et al., 2020). Therefore, this study aims to answer – in accordance with the previously defined objectives – the following main research question:

Main Research Question: How can blockchain technology be used to improve supply chain management towards a circular economy?

The main research question is divided into three separate sub-questions:

Sub-question 1: *What is the underlying relationship between blockchain technology and supply chain management?*

Sub-question 2: *What is the underlying relationship between blockchain technology and circular economy?*

Sub-question 3: *What is the underlying relationship between supply chain management and circular economy?*

1.4 Structure of the thesis

This thesis is divided into four sections to answer the main research question. The first section provides the reader with a thorough literature review that outlines the theoretical framework of this study. The theoretical framework is derived from the formulated sub-questions and describes the underlying relationships between blockchain technology, supply chain management, and the circular economy based on previous research. The second section describes the methodology used for this study. The third section begins with an overview of the main results related to the formulated sub-questions of this research. It then analyzes in detail which possibilities and opportunities blockchain technology can offer supply chain management to promote the circular economy. A system architecture has been developed to guide the analysis. Finally, the fourth section closes with a conclusion in which practical implications of this research are also discussed, and future research is recommended.

2. Literature Review

2.1 Definitions

Blockchain Technology

Blockchain technology is defined by Casino et al. (2019) as a distributed ledger technology (DLT) organized as a list of ordered blocks, where the committed blocks are immutable. Kshetri (2021) identified three key features of blockchain technology: decentralization, immutability, and provability. On the distributed network of a blockchain, all participants are linked together through multiple communication paths, transferring ownership of value among themselves in a transparent manner without the help of external parties (Morabito, 2017). This eliminates the dependency on a central node and ensures that the data recorded on the blockchain cannot be manipulated. The immutability function of blockchain technology makes transactions verifiable which ensures a higher degree of transparency (Kshetri, 2021). Although the idea of a cryptographically locked chain of blocks of data was originally developed by Haber and Stornetta (1991), research by Nakamoto (2008) provided new insights to the idea of a distributed digital transaction network (Lumineau et al., 2021). The potential of blockchain technology was initially noticed in financially oriented applications, but it is not limited to this. Lu (2018) argues that blockchain technology is not limited to capital markets and cryptocurrencies but could also conduct in-depth exercises in non-financial applications and platforms such as the energy sector (Andoni et al., 2019), e-governance (Lumineau et al., 2021), and supply chains (Caldarelli et al., 2021).

Table 1 *Blockchain Types segmented by Permissions (adapted from Hileman & Rauchs, 2017, p. 20)*

			Read	**Write**	**Commit**
Blockchain Types	Open	*Public permissionless*	Open to anyone	Anyone	Anyone
		Public permissioned	Open to anyone	Authorized participants	All or subset of authorized participants
	Closed	*Consortium*	Restricted to an authorized set of participants	Authorized participants	All or subset of authorized participants
		Private permissioned	Fully private or restricted to a limited set of participants	Network operator only	Network operator only

As shown in *Table 1*, different blockchain types can be segmented that differ in their corresponding read, write, and commit rights of the network participants. When configuring a blockchain network, these permissions can be set: read (who can access the network), write (who can generate and send transactions to the network), and commit (who can update the state of the network). The type of blockchain and the following rights are crucial to its application and context, as it influences access to and modification of the information on the blockchain that determines the degree of centrality and transparency (Böckel et al., 2021). For example, an open blockchain may be more suitable for matters of public interest, while a closed blockchain might be better used to store sensitive corporate data. However, it can be assumed whether a closed blockchain is actually a 'blockchain' since the permissions of network participants limit the primary functions of blockchain technology (Kouhizadeh et al., 2019).

Supply chain management

The concept of supply chain management has evolved as a result of increased competition, globalization and outsourcing and has been used to describe the complexity of business-to-business (B2B) and business-to-consumer (B2C) networks (De Angelis et al., 2018). *Supply chain management* can be defined as the management of upstream and downstream relationships with suppliers and customers to deliver outstanding customer value at a lower cost to the supply chain as a whole (De Angelis et al., 2018). Effective logistics services play a critical role in a company's ability to deliver value to its customers, with supply chain management striving to get products on time, in the right condition, and at the lowest possible cost (Flint, 2004). Supply chain management performance is often measured against objectives such as speed, reliability, quality, cost, and flexibility (Kshetri, 2018). These objectives demonstrate that traditional supply chains focus on linear thinking around inputs and outputs, with supply chain management focusing on multiple customer-supplier relationships beginning from raw material extraction to the end consumer (De Angelis et al., 2018).

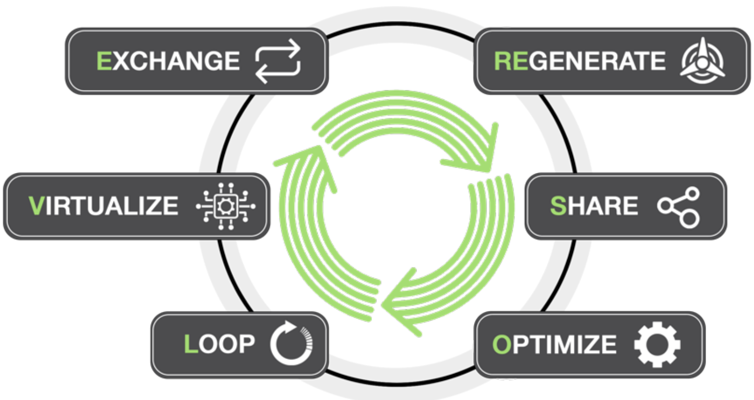
Global supply chains are inherently complex with globalization and different cultural and human behaviour, making it nearly impossible to assess information and manage uncertainties (Saberi et al., 2018). Trust is recognized as one of the critical factors in the close relationship and collaboration between supply chain stakeholders (Chang et al., 2019). However, inefficient transactions, fraud, and underperforming supply chains have led to more significant trust deficits creating a need for better information sharing and transparency. Moreover, traceability has become an increasingly urgent requirement in many supply chain industries. For example, luxury and high-value goods whose provenance depends on paper certificates and receipts can be easily altered or lost, and the true value of these goods cannot be verified and validated (Saberi et al., 2018). The costs associated with traceability, transparency, reliability, and collaboration with stakeholders make the management of complex supply chains very complicated (Saberi et al., 2018).

Circular Economy

Although there is currently no consensus in academia on the concept and definition of a circular economy (Kirchherr et al., 2017), this research assumes that the term 'circular economy' refers to a restorative and regenerative economic industrial system designed to minimize waste generation and maximize resource efficiency and environmental sustainability while preserving the value of materials, products and resources in the economy for as long as possible (Böckel et al., 2021; Geissdoerfer et al., 2017). The volatility of commodity prices caused by growing modern economies, a burgeoning number of middle-class consumers entering the market, and increasing regulatory pressures targeting climate change and waste are some factors that question the feasibility of traditional linear economic models according to the take-make-dispose approach (De Angelis et al., 2018). While linear economic models only downcycle end-of-life products to produce something with less value than the original, circular economy focuses on upcycling end-of-life products so that these products can be reused over and over at the end of their useful life to maintain their value (Wang et al., 2020). A circular economy contributes enormously to the transformation of industry towards a more climate-neutral and planet-sustainable approach, generating additional value, revealing economic opportunities, and significantly saving materials in the value chains and production processes (Alves et al., 2021). Circular economy systems deviate from the traditional take-make-dispose approach and instead use reduction, reuse, recycling and recovery within a closed system (Kirchherr et al., 2017). This regenerative approach is reflected in the ReSOLVE framework (*Figure 2*) established by the Ellen MacArthur Foundation and proposes six principles guiding the transition to a circular paradigm: regeneration, sharing, optimization, loop, virtualization, and exchange (MacArthur et al., 2015).

Regeneration encompasses the shift from fossil fuels to renewable energy and materials, the recovery and storage of energy and materials for natural ecosystems, and the return of recovered raw material sources to the biosphere. Sharing is embedded in the perspective of a "sharing economy", in which goods and assets are maximized and waste and duplication are minimized. This ReSOLVE principle focuses on sharing, reusing, and repairing goods and materials, replacing reproduction with the circular economy to extend the life cycle of products. Optimization focuses on reducing non-value-adding activities in production, exploitation, and consumption processes (Kouhizadeh et al., 2019). Moreover, optimization also includes the application of digital manufacturing technologies (e.g., big data, sensors, automation) to improve product performance, maximize resource efficiency, and reduce waste in supply chains (Lopes de Sousa Jabbour et al., 2018). Loop refers to the direct opposite of the traditional linear paradigm; instead of the make-use-dispose approach where resources and materials follow a linear path to landfills, resources and materials are recollected, recycled, and remanufactured in a closed loop (Kouhizadeh et al., 2019). Virtualization refers to a service-oriented strategy that encourages dematerialization by replacing the physical use of goods with virtual and materialized products. Finally, exchanging focuses on upgrading production processes by adopting new technologies that replace old and non-renewable materials with advanced and renewable materials (Lopes de Sousa Jabbour et al., 2018).

Figure 2 *ReSOLVE Framework (adapted from MacArthur et al., 2015)*



2.2 Relationship between blockchain technology and supply chain management

As noted earlier in the literature review section, supply chain management faces common challenges such as traceability, transparency, reliability, and stakeholder collaboration. When supply chain stakeholders fail to deliver requested products completely and on time, they usually have to solve these problems through fines or compensation. For example, US retail corporation Walmart began fining suppliers for failing to deliver at least 85 percent of their shipments on time in 2018 (Chang et al., 2019). However, disputes arising between involved supply chain parties due to identified supply chain issues are generally time-consuming and expensive to resolve. According to Chang et al. (2019), these disputes mainly arise from ambiguities in contract terms and a lack of accountability. Blockchain technology offers the unique opportunity to capture the transfer of ownership, legality and safety requirements in real-time, thereby solving supply chain problems and minimizing the potential for disputes (Chang et al., 2019). *Smart contracts* can be introduced in supply chain management that automatically enforce fines or compensation at low procedural costs if predefined conditions are violated (Chang et al., 2019). Smart contracts are automated transaction protocols that contain pre-written business rules and conditions stored on a particular blockchain network (Alves et al., 2021; Kouhizadeh et al., 2019). Smart contracts can be thought of as a complex *if-then* statement: if and only if a set of embedded conditions are met, a smart contract ensures that the associated activity of these conditions is automatically executed without human intervention (Grecuccio et al., 2020). Once a smart contract is implemented on a blockchain network, the transaction protocol cannot be changed and is always executed according to predefined conditions (Alves et al., 2021). Because blockchain technology provides real-time insight into the supply chain to ensure that all smart contract conditions are met, blockchain technology offers a reliable mechanism for all supply chain stakeholders whereby communication problems can be effectively reduced (Chang et al., 2019; Kouhizadeh et al., 2019).

Traceability and transparency are two other supply chain management challenges where opportunities and opportunities lie for blockchain technology to address these issues. While traceability in the past has mainly focused on upstream supply networks where the origin and details of raw materials and resources were tracked, supply chain management was later extended to include downstream capabilities where goods can be traced along multi-layer distribution networks to the end-user (Chang et al., 2019). However, most companies are currently still struggling to obtain accurate and up-to-date information for effective operation throughout the supply chain (Kouhizadeh et al., 2019). In addition, traditional supply chain management does not provide a reliable and efficient way to verify the origin and details of products and resources due to a lack of transparency and traceability (Chang et al., 2019). The 2015 E.coli virus outbreak at Chipotle Mexican Grill stores that left dozens of customers sick is a clear example of the severe lack of transparency and traceability that complex supply chains currently face. This outbreak caused significant image problems for Chipotle due to adverse news reports, restaurant closures and investigations that caused their stock price to drop by 42% (Kshetri, 2018). After months of investigation, Chipotle and the Centers for Disease Control and Prevention were still unable to pinpoint the exact source of the contamination (CDC, 2019). In the context of traceability, blockchain technology and associated tracking capabilities (e.g., GPS: *Global Positioning System*) can provide a fully documented string of transaction data for all different participants in the supply chain. In addition, blockchain technology offers the possibility to add transparent, verifiable, and immutable records in the form of digital certificates to the origin of products and resources (Chang et al., 2019). Therefore, supply chains would have immutable tamper-resistant distributed data records providing accurate real-time information about material and product flows (Böhmecke-Schwafert et al., 2022). Blockchain technology could therefore improve traceability for supply chain management which provides governments, companies and consumers with irrefutable proof of the origin and authenticity of products and resources to tackle fraud and promote sustainability. In addition, blockchain technology can deliver greater transparency across the entire value chain, making it possible to identify the source of problems more efficiently and accurately in the event of a product recall or contamination epidemic such as the E.coli outbreak at Chipotle.

2.3 Relationship between blockchain technology and the circular economy

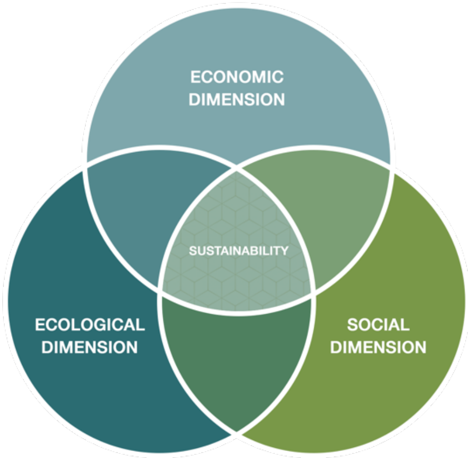
Increasing digitization makes it possible to realize the vision of a regenerative and resilient circular economy (Upadhyay et al., 2021). This mainly includes Industry 4.0 technologies such as artificial intelligence, big data analytics, and the internet of things (IoT) where blockchain technology has the potential to advance Industry 4.0 technologies and support circular economy progress in various ways (Kouhizadeh et al., 2019; Upadhyay et al., 2021). In relation to the ReSOLVE framework, blockchain platforms can effectively address the principles of *sharing*, *optimization*, *visualization*, and *exchange* that create sustainable digital opportunities for a circular economy (Upadhyay et al., 2021). Several requirements must be met to achieve a circular economy, such as circular product design, closing material and energy cycles for material collection in reuse or recovery, and underlying system conditions (Böckel et al., 2021). One of these underlying system conditions is an infrastructure for collaboration platforms and information sharing with involved stakeholders – such an infrastructure is crucial for a circular economy as shared and transparent information forms the basis for setting up different resource and material flows (Böckel et al., 2021). Such an information infrastructure could be built on a blockchain allowing blockchain technology to take sustainability practices to the next level. The origin of materials products, production and operation processes, energy consumption, and end-of-life cycle are exemplary information that can be made available on blockchain networks. For example, blockchain technology and associated tracking capabilities can enable the tracking of materials and products throughout their lifecycle and support a reduction in resource use. These potential blockchain functions can form the basis for reuse, upcycling, recycling programs and sustainable supply chain management in combination with smart contracts (Kouhizadeh et al., 2019). Blockchain technology and smart contracts can facilitate the automation of transaction processes in a permanent and verifiable manner, saving time and resources and eliminating inefficiencies or waste (Upadhyay et al., 2021). For example, smart contracts can help prevent product degradation in advance by sending real-time alerts for inspection as soon as IoT sensors in a container indicate that required environmental conditions are being violated (Chang et al., 2019). While there are several other possibilities for using blockchain technology in a sustainability context, it can be suggested that the sustainability of supply chain management is one of the most important use cases (Saberi et al., 2018).

2.4 Relationship between supply chain management and the circular economy

Over the past three decades, there has been a significant increase in interest in the literature and practice in the associations of supply chain management with sustainability (De Angelis et al., 2018). Research by Carter and Rogers (2008) was the first to establish a relationship between sustainability within a supply chain management context, where sustainability was understood as a triple-bottom-line concept: a balance between ecological, social, and economic dimensions

(*Figure 3*). Regarding the intersection of these three dimensions, the researchers stated that there are activities for organizations that could result in long-term benefits and competitive advantages while also having a positive impact on the natural and social environment (Carter & Rogers, 2008). Therefore, a closed-loop supply chain approach was advocated to reduce resource dependency and uncertainty and achieve long-term economic sustainability (De Angelis et al., 2018). Today, the growing awareness that sustainability must be considered throughout the supply chain has led to the emergence of the sustainable supply chain management paradigm (Hussain & Malik, 2020). Hussain and Malik (2020) define sustainable supply chain management as the management of material, capital, and information flows and cooperation among supply chain actors while considering the triple-bottom line. However, despite sustainable supply chain management emphasizing the triple-bottom-line concept, sustainable supply chain management practices to date have mainly focused on minimizing the ecological footprint of supply chain activities and reducing resource use in production processes (Hussain & Malik, 2020). This focus of sustainable supply chain management on cleaner production and resource efficiency in supply chains has been described by Loiseau et al. (2016) as "weak sustainability" as it is implicitly assumed that resources are available in abundance. In contrast, "strong sustainability" requires fundamental changes in the way goods and services are produced and consumed to conserve the limited resources available in closed material and energy cycles (Hussain & Malik, 2020).

Figure 3 *Triple-bottom-line Concept (adapted from Carter & Rogers, 2008, p. 365)*



While sustainable supply chain management has adopted some of the regenerative strategies of the circular economy (e.g., reducing, reusing, and recycling) aimed at reducing the environmental impact of supply chain processes, circular supply chain management goes a step further by adopting a zero - apply waste vision and ensure that value recovery is also enabled. Circular supply chain management can be seen as strong sustainability and is defined by Farooque et al. (2019) as the integration of circular thinking into the management of the supply chain and the surrounding industrial and natural ecosystems. However, a radical shift to circular supply chain management is not easy to implement as product recycling has rarely been regarded as a value-creating system to date (De Angelis et al., 2018). In addition, circular supply chain management requires significant investment in resources to understand the configuration of information flows and parts distribution and develop a collection system that takes products back at the end of their lifecycle (De Angelis et al., 2018). Circular economy processes such as remanufacturing and recycling products can be very complicated as the condition of used products can vary greatly, so that products must still be discarded after retrieval if they are irreparably damaged. Circular supply chain management must be capable of combining traditional supply chain management activities aimed at efficiency and cost savings with circular supply chain management activities such as reverse logistics and product repair/refurbishment (De Angelis et al., 2018). For example, reverse logistics is a circular supply chain management activity that is required to recycle, recover, and reuse materials and products. However, traditional reverse logistics struggle to obtain accurate information about the quality and condition of materials and products due to the complex nature of the multi-layer supply chain processes (Kouhizadeh et al., 2019). Even though reverse logistics systems have been put into practice since the early 20th century, there is still a lack of strategic motivations necessary to integrate the concept of reverse logistics into supply chains with closed material and energy cycles (De Angelis et al., 2018).

3. Methodology

This thesis investigates the possibilities and opportunities of blockchain technology in supply chain management to encourage a circular economy. Exploring the complex relationships between the integration of blockchain technology into supply chain management to promote the circular agenda allows for an in-depth understanding and clear vision of these complex dynamics. The central aim of this study is to bridge the research gap on the adoption possibilities of blockchain technology in supply chain management that can promote circular economy practices. While this study will not necessarily close the gap at the intersection of blockchain technology, supply chain management, and circular economy, it attempts to bridge this gap by analysing potential application areas. To achieve the aim of this study, qualitative data collection and analysis methods are applied.

3.1 Research design

The design of this qualitative research is exploratory in nature. Saunders (2012) argues that exploratory research is aimed at developing new insights and clarifying a basic understanding of a phenomenon, applying this research method mainly to topics where little research and knowledge is available. A qualitative exploratory study appears appropriate as there is no extensive literature or theories on the integration of blockchain technology in supply chain management in the context of a circular economy. At the same time, due to its novelty, blockchain technology has not yet been adopted sufficiently in supply chain management to make quantitative statements about possible application areas in practice. To answer the research question and related sub-questions, this research will use an abductive approach. As advocated by Dubois and Gadde (2002), an abductive approach is fruitful when a phenomenon has a high degree of novelty and the study aims to explore the underlying variables and their relationships. The approach involves identifying a particular phenomenon and then linking it to broader concepts by systematically combining scientific literature and empirical data (Dubois & Gadde, 2002). Therefore, an abductive approach allows the researcher to explore the possibilities and opportunities of blockchain technology for supply chain management from a broader perspective of the transition to a circular economy, thereby inferring the underlying relationships between the relevant concepts.

3.2 Data collection

Existing literature has formed a foundation for this research for the design of the questionnaires for the qualitative interviews. The large-scale digital databases SmartCat, Scopus, and Google Scholar were used to obtain scientific literature. Primary keywords included: “blockchain technology”, “smart contracts”, “industry 4.0 technologies”, “supply chain management”, “circular economy”, and “adoption”. To determine the relevance of the acquired literature, sources were scanned by their title and abstract, with sources being included if the identified keywords were visible in the title and/or abstract. By adopting a snowball approach, additional relevant sources were identified from the citations of sources included in the synthesis. In addition, duplications were removed due to the parallel search flows. Ultimately, 45 sources were included in the synthesis, consisting of peer-reviewed academic journal articles and chapters from academic books.

In qualitative research methods, semi-structured interviews are an important data collection strategy as they can facilitate detailed descriptions of the participants’ perspectives and experiences on a phenomenon (Baumbusch, 2010; Lambert & Loiselle, 2008). The semi-structured interviews for this study included a series of open-ended questions, which according to Ryan et al. (2009) allow for spontaneous and in-depth answers. Selecting suitable participants for semi-structured interviews is vital (Clifford et al., 2016, p. 148). This study focused on representatives and experts from organisations, companies, or government institutions, with the respondents being selected based on the criteria that they had adequate knowledge about blockchain-based systems for supply chain management that promote circular economy activities. Due to the confidentiality of this study, the names of the representatives and experts contacted will not be released. To further expand the initial selection of research participants, respondents were kindly asked to share contact details of other relevant experts at the conclusion of the semi-structured interviews. In total, seven semi-structured interviews were conducted with an average duration of 1 hour and 2 minutes (*Table 2*) over a period of 3 months. Potential participants were approached via email, LinkedIn, or online contact forms, where they were asked if they were willing to participate in this study through a semi-structured interview. A friendly reminder was sent if no response was received after three weeks and a direct email address was known. The semi-structured interviews were conducted via the video conferencing platforms Zoom, Microsoft Teams, and Google Meet.

Table 2 *Overview of Interviewees*

Set of interviews				
No.	**Length**	**Position**	**Area**	**Organization type**
1.	1 h 3 min	Professor	Research	Academic institution
2.	1 h 9 min	Professor	Research	Academic institution
3.	0 h 56 min	Founder	Supply Chain	Private organization
4.	1 h 13 min	Professor	Research	Academic institution
5.	0 h 31 min	Managing Director	Consultancy	Private organization
6.	0 h 38 min	Senior Partner	Consultancy	Private organization
7.	1 h 47 min	Founder	Blockchain Technology	Private organization

According to Ryan et al. (2009), developing an interview guide is key to obtaining data that addresses the purpose and objectives of the study. Using an interview guidethe focus of the semi-structured interviews was on the descriptions and experiences of participants, thereby avoiding guidance towards specific desirable answers. The interview guide (see Appendix A) started with questions about the utilisation of Industry 4.0 technologies and the practical integration of blockchain technology in supply chain management. Subsequently, questions were asked about the functionality of blockchain technology concerning supply chain management and circular economy activities. Finally, questions were asked about what obstacles could affect the integration of blockchain technology in supply chain management to promote a circular economy. At the end of the semi-structured interviews, respondents were asked if they had any additional comments to ensure no essential aspects were overlooked. The interview guide was wholly derived from the previous literature review section.

3.3 Ethical considerations

The highest standards were conducted throughout the study, with all participants treated with respect and courtesy. Prior to the semi-structured interviews, respondents were informed about the study and asked to sign a consent form (see Appendix B). In addition, respondents were asked for permission to record the semi-structured interviews. While extensive verbatim excerpts from the semi-structured interviews were used in the data analysis, audio recordings of the semi-structured interviews were repeatedly re-evaluated to ensure faithfulness to the respondents' original narratives.

3.4 Data analysis

According to Timmermans and Tavory (2012), an abductive approach requires a deepening understanding of the scientific literature before analysing data. After audio recordings of the semi-structured interviews were transcribed, the qualitative analysis software MAXQDA was used to encode the data. The coding process followed the approach of Gioia et al. (2013) to ensure the highest possible qualitative accuracy. The data was scanned for patterns enabling indexing of themes based on analytical categories. By continuously switching between the collected data and theory, patterns and thematic focus areas could be identified and compared with existing theory and findings from the literature review. In total, four codes were identified that index the textual data: "digitisation and automation", "blockchain services", "applications for circular economy", and "considerations".

4. Analysis and discussion

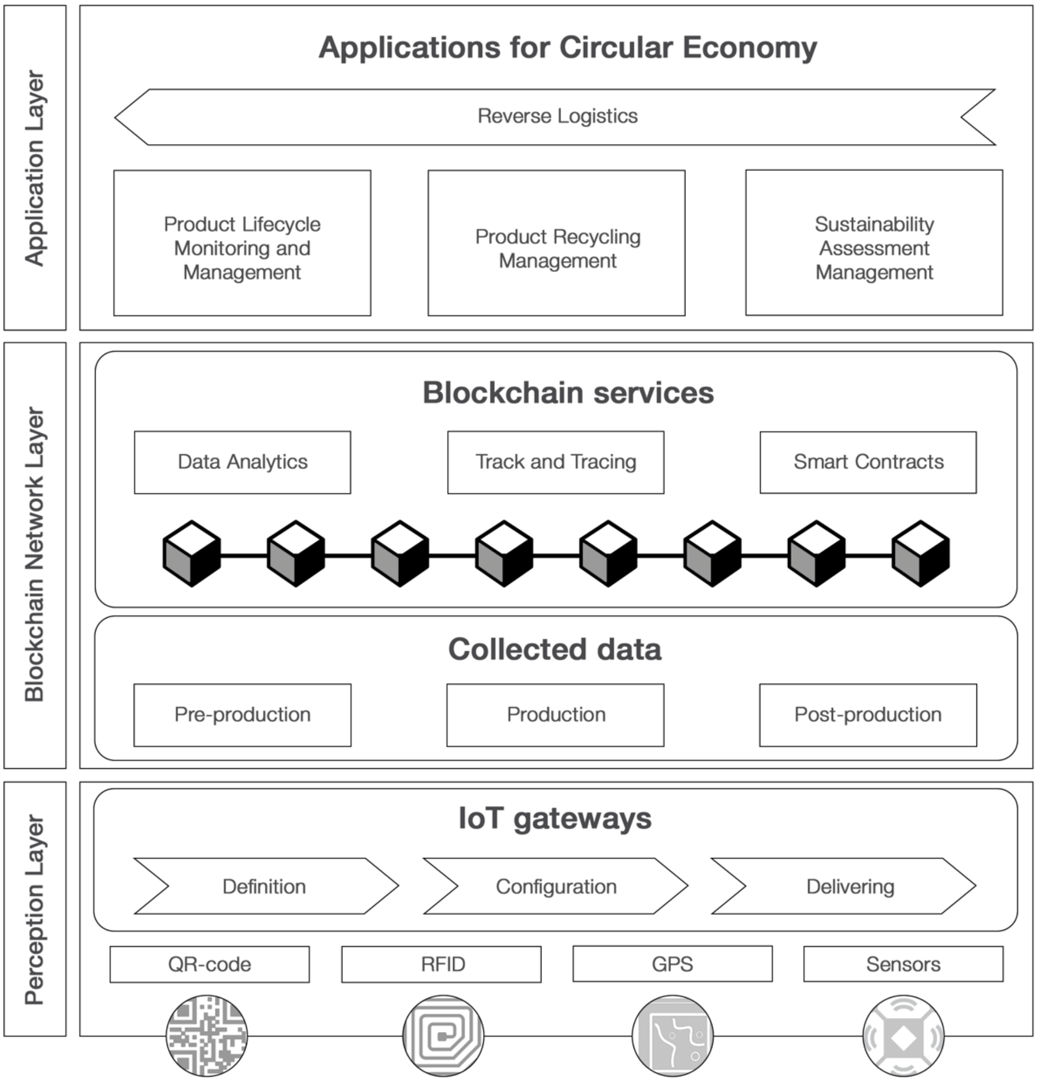
Regarding the relationship between blockchain technology and supply chain management, respondents mainly spoke about traceability capabilities and the implementation of smart contracts. Respondents described supply chain traceability and transparency as the track and tracing of all data and transactions, where supply chain stakeholders can follow raw materials and the transitions that products go through from source to destination. Respondents stated that blockchain technology can help ensure a higher degree of traceability and transparency in the complex multi-layered supply chains. All respondents also spoke about the implementation of smart contracts, arguing that the automatic agreements of smart contracts ensure that supply chain stakeholders are disconnected from traditional contract agreements. Smart contracts provide the assurance that all contracts throughout the supply chain are exactly the same, minimizing the potential for disputes. In addition, it was argued that the automatic verification of agreements between supply chain stakeholders allow smart contracts to be used for quality control – supply chain stakeholders can thus be checked whether they comply with the quality and sustainability requirements.

Regarding the relationship between blockchain technology and the circular economy, it was mainly indicated that work is still being done to translate the circular economy into a business process effectively. Respondents stated that blockchain technology is currently not seen as a profitable investment for circular economy practices – mainly due to few practical use cases. However, the respondents emphasized that blockchain technology in combination with Industry 4.0 technologies can provide companies with greater insight into their business processes. In that case, blockchain technology could help ensure the data's reliability.

Regarding the relationship between supply chain management and circular economy, respondents mainly stated that all supply chain stakeholders should systematically work together to integrate the concept of a circular economy into supply chain processes. Ideally, when supply chain stakeholders establish this collaboration, innovative business models and relevant supply chain functions could be developed to apply a zero-waste vision by upcycling all relevant resources throughout all production stages of the product lifecycle. Five respondents emphasized that manufacturers should be held accountable for incorporating reverse logistics into their business processes. Manufacturers should not only ensure that their production processes meet sustainability requirements but also have an obligation to take back products.

To answer the research question of this study, the next section will analyze the possibilities and opportunities blockchain technology can offer supply chain management to promote the circular economy. To guide this analysis, a system architecture has been developed (*Figure 4*) comprising three technical layers: perception layer, blockchain network layer, and application layer. The proposed system architecture shows 1) the way data can be collected during all phases of the product lifecycle, 2) the blockchain services for supply chain management, and 3) four main applications of blockchain technology for supply chain management to promote circular economy activities.

Figure 4 *System Architecture*



4.1 Perception layer

Before going into specific detail about the services of blockchain technology in supply chain management, it seems expedient and necessary to discuss the need for digitization and automation. The analysis suggested that many companies face a significant challenge in digitizing and automating their business processes. In the words of Respondent 7: "The first step is actually a need for digitization and automation – which often involves more insight into the data of their business processes. Once people have insight into this data, it is easier to make choices." Respondent 3 added: "The real challenge is connecting the disconnected things. In fact, what needs to happen is that physical actions need to be digitized." Industry 4.0 technologies such as the Internet of Things (IoT) could connect the real world with the digital world. Therefore, Industry 4.0 technologies reside at the perception layer of the proposed system architecture, allowing data to be collected throughout all phases of the product lifecycle. This process of automatic data collection is mainly performed by IoT technologies such as QR codes, RFID tags and readers, GPS, and sensors. Respondents stated that these IoT technologies could be applied in the pre-production phase to prepare materials for digitization. Materials are given a digital identity that allows comprehensive information (e.g., quality, quantity, and characteristics) of the materials to be easily identified at any stage of the supply chain. Respondent 2 noted that "the capabilities of these automation technologies allow databases to be enriched with insightful data, which can be further expanded in the production and post-production phases." Respondents identified various data that can be collected in both production phases, such as working conditions, environmental impact, production and distribution processes. As a result, the automatic data collection process provides greater visibility into the production steps that have been undertaken, resulting in a higher degree of transparency and accountability within the supply chain. However, several respondents believed that the real gains are not in Industry 4.0 technologies, but rather in what is done with the collected data, as supported by Respondent 2: "While Industry 4.0 technologies help us to retrieve data much better and connect it to materials and products, the traditional databases and information systems behind them greatly determine what can be done with this information."

Respondents suggested that the collected data from all stages of the product lifecycle should then be transferred to IoT gateways, where the data is preprocessed. Respondent 1 described these IoT gateways as intermediaries between wireless sensor networks and traditional communication networks that are employed to transfer the collected data to blockchain networks. The data preprocessing by IoT gateways consists of defining and configuring the collected data (e.g., the origin of raw materials), after which the data is sent from the perception layer to the blockchain network layer.

4.2 Blockchain network layer

Real-time

The literature review section described that blockchain technology offers the unique ability to record collected data and information in real-time. Real-time means that a time span is agreed upon on the delay time within which data becomes visible in a particular information system. While all respondents recognized the critical importance of real-time data recording, they also emphasized that the real-time aspect depends on the application and context of the blockchain-based system architecture. Respondent 5 illustrated this in the following statement: "In some situations, real-time is not feasible. For example, data about the contents of a container on a freighter cannot be provided in real-time if there are no transceivers. In such situations, data is sent in batches when there is an occasional receipt. So, in principle, data can be sent to any decentralized location, as long as it has a connection to the blockchain network." Therefore, the analysis revealed that supply chain stakeholders must have clear agreements about the time frame within which data should be delivered.

Reliability

In line with the literature review section, all respondents recognized that trust, traceability, transparency, and stakeholder collaboration are significant challenges for supply chain management in practice. The analysis suggested that a relationship can be observed between the identified challenges of supply chain management: improving traceability and transparency leads to the promotion of trust. As Respondent 7 put it: "The extent to which digitization and automation in combination with blockchain technology are used to properly arrange traceability and transparency ultimately contributes to higher reliability in the supply chains. The more companies can show where their materials come from, what happened to them, and how it was treated, the better it contributes to trust." All respondents confirmed that trust is one of the most critical factors for supply chain management due to the need for stakeholders to trust that operations in the supply chain are performed according to the predefined agreements. The analysis pointed out that everything revolves around the agreements that have been made with each other and how they are proven. From a technical point of view, many systems and protocols have been set up (e.g., certifications, ISO standards) that guarantee these agreements as a paper reality to create a certain form of trust. For example, a company can demonstrate with ISO standards that the way in which they operate meets certain quality requirements. However, several respondents indicated that there is much cheating with these traditional systems and protocols in practice. Instead, digitization and automation in combination with blockchain technology can be deployed so that supply chain stakeholders are given little room to deviate from their processes. This would help to move away from a paper reality and towards an honest reflection and representation of industrial processes.

Data storage

The blockchain network layer of the proposed system architecture is responsible for capturing the data sent from the IoT gateways. However, there was no consensus among the respondents on how data could be stored on a blockchain network. Storing data is a technical implementation issue that depends on how the blockchain network is set up. For starters, one has the option to put all data on the blockchain network. However, blockchain technology is primarily a distributed database for transactions but is usually not very useful for storing large amounts of data. Therefore, one also has the option to generate hash values that are stored on the blockchain network and associated with a particular transaction. As Respondent 6 explained, the hashed setup of a data string can be used as identifiers on the blockchain network with the data stored on a separate database. The steel industry can be taken as an example to illustrate the application of hash values. Steel is made from a specific composition of ingredients that must be certified. For this certification, data from the production processes can be put in a separate database, where the data is then hashed, and only the hash values are stored on the blockchain network. The hash values guarantee that the data is immutable – stakeholders will always get back the same hash values if the data is not manipulated. Therefore, required certificates can be created based on these hash values to prove that the steel has been produced according to the correct specifications.

Services

Based on the analysis, this research determined that the blockchain network layer of the proposed system architecture provides three essential services to store data and contribute to supply chain management: data analytics, track and tracing, and smart contracts. First, the analysis suggested that data analytics can be performed on a blockchain network where processed data is analysed, identified, and clustered for valuable and important information. By utilising machine learning algorithms, data mining technologies and various mathematical models, data analytics can discover meaningful patterns and deliver accurate and updated information. Therefore, stakeholders gain a better understanding of the supply chains, thus enabling them to organise their decision-making better.

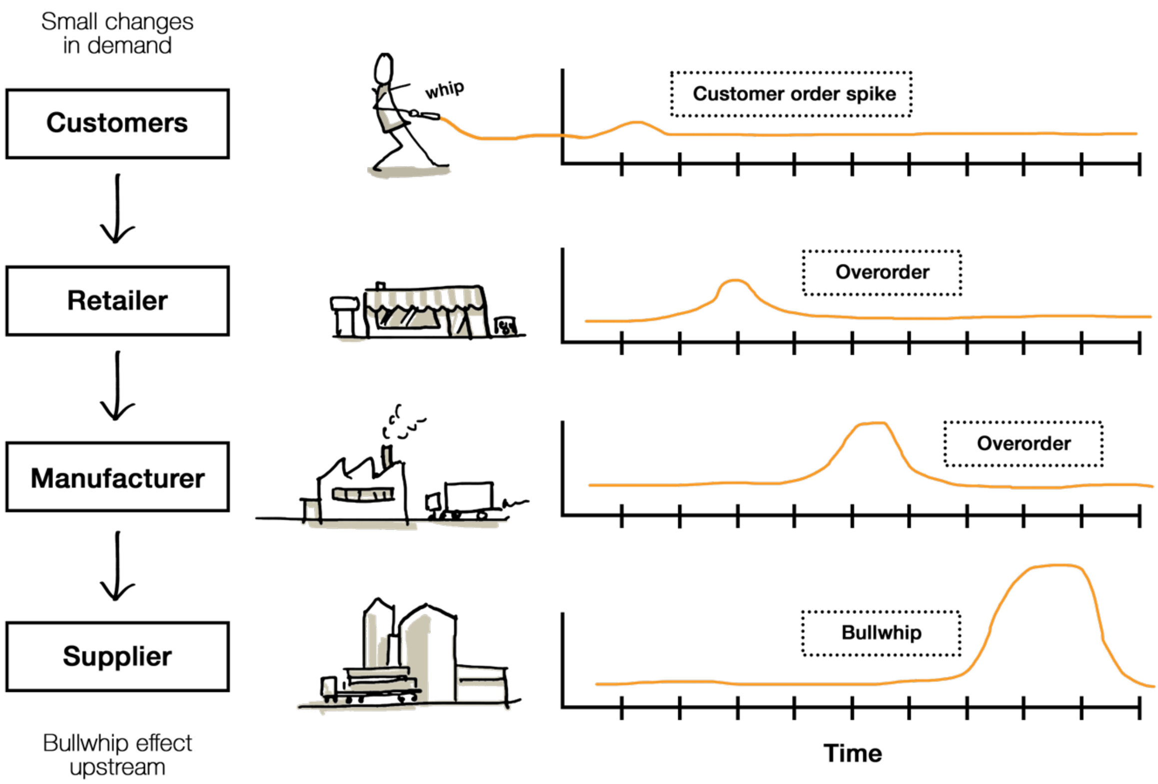
Secondly, the analysis showed that blockchain technology is mainly used for track-and-tracing in practice. These traceability services enable supply chain stakeholders to trace data throughout all product lifecycle stages. As suggested in the literature review section, the analysis confirmed that blockchain technology could verify the origin of products and resources in supply chain management. Respondent 2 gave the following statement: “If it is chosen to put hash values on the blockchain network, then hash values offer the property of non-mutability. If the stored data is tampered with, this is visible to all stakeholders. In this way, blockchain technology can ensure that stakeholders gain reliable insight into all supply chain activities from the start of the extraction of raw materials." However, it should be noted that these traceability services again depend on specific infrastructure requirements that can affect the implementation of a blockchain network.

Finally, the analysis showed that the implementation of smart contracts is one of the most transformative use cases of blockchain technology. However, it was emphasized by all respondents that the functionality of smart contracts depends on the way it is written. Smart contracts are nothing less than self-executing lines of code where the terms of an agreement between stakeholders are automatically verified and executed via the blockchain network. So when smart contracts are poorly written, they will not function properly. In the words of Respondent 2: "It is extremely important how a blockchain network is designed and the processes that are agreed, but ultimately smart contracts also determine the efficiency and effectiveness of the use of blockchain technology in supply chain management." Therefore, huge consideration must be given to the terms being written when applying smart contracts.

4.3 Application layer

The application layer of the proposed system architecture offers four main applications of blockchain technology for supply chain management to promote circular economy activities: product lifecycle monitoring and management, product recycling management, sustainability assessment management, and reverse logistics.

Figure 5 *Bullwhip Effect in Supply Chain Management*



Product lifecycle monitoring and management

The literature review section stated that blockchain technology could be applied as an information infrastructure that can take sustainability practices to the next level. It was suggested that blockchain technology and smart contracts could facilitate the automation of transaction processes in supply chain management in a permanent and verifiable manner, saving time and resources and eliminating inefficiencies or waste. The analysis revealed that blockchain technology could be applied within supply chain management to reduce overproduction, mainly related to the 'optimization' principle of the ReSOLVE framework. In the linear structure of traditional supply chain management, only two adjacent nodes have the proximity to share information partially. This causes consumer demand information to be scrambled towards upstream suppliers, which is usually reinforced by buffer considerations. Respondent 1 stated that this demand distortion could cause a bullwhip effect (*Figure 5*). The bullwhip effect has been defined as a supply chain-wide phenomenon where orders to suppliers tend to have a greater variance than sales to consumers (i.e., demand distortion), and the distortion propagates upstream in an amplified form creating larger discrepancies. Therefore, linear economic models in traditional supply chain management generate a tremendous amount of waste through overproduction. A traditional solution to reduce the bullwhip effect is to collect centralized information about consumer demand. However, this requires clear communication between supply chain stakeholders, which is difficult due to severe trust deficits and a lack of complete information sharing in complex multi-layered supply chains. Respondents suggested that blockchain technology offers the opportunity to create a trust-free distributed network with peer-to-peer asset databases, providing supply chain management with enhanced traceability, transparency, reliability, and stakeholder collaboration. With blockchain technology, supply chain stakeholders can accurately adjust their individual activities and production, which in turn leads to a reduction in inventory quantity throughout the supply chain. By empowering all supply chain stakeholders to jointly forecast consumer demand, the bullwhip effect is minimized and production waste can be significantly reduced.

Product recycling management

The literature review section stated that a radical shift to a circular economy is not easy to implement, as supply chain stakeholders rarely regard product recycling as a value-creating system. All respondents agreed with this statement, with lobbying being the main reason. As Respondent 7 explained: "The interests are simply too great. Nowadays, the entire economy runs on pure consumption, so you just run into the interests of big industry." Moreover, the literature review section emphasized that circular economy practices such as remanufacturing and recycling products can be very complex as the condition of used products can vary widely, requiring products to be discarded after retrieval if they are irreparably damaged. The analysis suggested that blockchain technology will allow manufacturers to verify and authenticate which materials can be recycled at the end of their life and which should be disposed of. Respondents stated that supply chain stakeholders currently struggle to predict which materials and products can be reused for other purposes. However, blockchain technology offers the opportunity to provide supply chain stakeholders with better insight into the components of products without taking them apart. According to respondent 5, this insight is acquired when supply chain stakeholders are capable of showing and proving where products come from. Respondent 5 described this in the following way: "By deploying Industry 4.0 technologies in combination with blockchain technology, supply chain stakeholders have the opportunity to find out the input factors of a specific product. Therefore, lists of input factors can be drawn up showing which materials and products can be reused."

Sustainability assessment management

Respondents stated that the complexity of the circular economy is not only a technical matter but also an organizational matter. Supply chains consist of a large network of stakeholders who all must work together to become circular. The respondents considered sustainability assessment management very important for incorporating circular principles into supply chain management. Companies are not only judged on their business qualifications, but also on their responsibilities towards sustainability. The analysis previously showed that data analytics in the blockchain network layer could deliver accurate and updated information to supply chain stakeholders. Respondent 1 stated that data on consumption and output emissions with blockchain technology could be easily shared and integrated to assess the environmental performance of supply chain stakeholders. Therefore, supply chain stakeholders can be selected and evaluated based on set sustainability standards. Policy frameworks can be translated into smart contracts to automatically check whether supply chain stakeholders comply with these policy frameworks that have been agreed upon with each other.

Reverse logistics

The analysis previously showed that blockchain technology is mainly used for track and tracing in practice. As a result, the amount of materials and products lost during logistics can be minimized, and all supply chain stakeholders can develop material supply resilience and resource efficiency contributing to the circular principles of the ReSOLVE framework. As the analysis previously found, Industry 4.0 technologies can help capture lifecycle data that can reveal the origin of products and resources. In combination with blockchain technology, this data becomes immutable, verifiable, and transparent, allowing blockchain technology to play an important role in reverse logistics. The literature review section stated that traditional reverse logistics struggle to obtain accurate information about the quality and condition of materials and products due to the complex nature of multi-layer supply chain processes. Respondents indicated that blockchain technology traceability services could enable stakeholders to track all transactions in the supply chain, making it easy to monitor and control the entire reverse logistics process.

However, the literature review section also emphasized that until now, there is still a lack of strategic motives needed to integrate the reverse logistics process into supply chains. The analysis suggested that a compelling framework is required to drive reverse logistics and circular economy further. Several respondents referred to the "right to repair" – a circular strategy whereby consumers are entitled to repair their (electrical) appliances instead of throwing them away. According to Respondent 6, the right to repair allows for more efficient and sustainable use of resources and encourages the reuse of products and the sharing economy. Finally, Respondent 4 argued for more research into the strategic motives needed to drive the reverse logistics process: "There should be more use cases that can yield results for research or opportunities for industries. At the moment there is just a huge research gap."

4.4 Considerations

The analysis emphasized that technical adoption choices are critical when setting up the blockchain network. The interpretation given to the system of design parameters (e.g., permissions, authorization, consensus, etc.) greatly determines the functionality of blockchain technology. There is no "one-size-fits-all" solution for this. Therefore, the context and application of blockchain technology for supply chain management should be considered to promote the circular economy. Respondents stated that blockchain technology is not *the* solution to all supply chain management challenges, but rather is an opportunity to be considered. In the words of Respondent 7: “You want to ensure that the agreements made with each other are complied with. And blockchain technology is an opportunity that can make that happen – but it’s not always the case. Contrary to what some people would like to believe.” The analysis found that many supply chain stakeholders are often unaware of their business processes and therefore choose solutions that do not effectively solve the issues they want to address. Therefore, the first step for supply chain stakeholders is to understand the data of their business processes better so that their decision-making process can be better organized and more effective solutions can be chosen. Only then does it become relevant to consider whether blockchain technology can add value to supply chain management to achieve a defined objective.

5. Conclusion

This study was intended to provide a clear insight into the possibilities and opportunities of blockchain technology in supply chain management to promote the circular economy. Using an abductive research approach, qualitative semi-structured interviews were conducted with representatives and experts from organizations, companies, and government agencies who had knowledge of blockchain-based supply chain management systems that could promote circular economy practices. A system architecture has been developed to guide the analysis.

The first technical layer of the proposed system architecture was the perception layer. Here, the analysis emphasized that supply chain stakeholders need to gain more insight into the data of their business processes so that their decision-making process can be better structured. Using Industry 4.0 technologies, supply chain stakeholders are enabled to collect data during all phases of the product lifecycle.

The second technical layer of the proposed system architecture was the blockchain network layer. The analysis showed that data analytics could be performed on the blockchain network, providing supply chain stakeholders with accurate and updated information. Blockchain technology's track and trace capabilities enable supply chain stakeholders to follow data throughout all product lifecycle production stages. Finally, it was found that the implementation of smart contracts is one of the most transformative use cases of blockchain technology. However, the analysis emphasized that the functionality of smart contracts depends on how it is written. Therefore, it is critical to consider the terms being written when applying smart contracts.

The third technical layer of the proposed system architecture was the application layer. The analysis revealed that blockchain technology could be applied within supply chain management to reduce overproduction. In addition, blockchain technology enables manufacturers to verify and authenticate which materials can be reused at the end of their life and which must be disposed of. Moreover, the analysis suggested that sustainability policy frameworks can be translated into smart contracts to automatically check whether supply chain stakeholders meet established sustainability standards. Finally, the analysis showed that blockchain technology's track and trace capabilities ensure that all supply chain transactions can be followed, making it easier to monitor and control the entire reverse logistics process. However, the analysis also revealed that a forced framework is required to drive reverse logistics and the circular economy further.

In general, the analysis stated that the interpretation given to the system of design parameters greatly determines the functionality of blockchain technology. It was emphasized that supply chain stakeholders must make clear agreements with each other and consider the application and context of blockchain technology when setting up the blockchain network.

This study has its limitations. The nature of this research is conceptual, as blockchain technology is not yet sufficiently adopted in supply chain management to promote the circular economy due to its novelty. In addition, it should be borne in mind that many supply chain stakeholders will not yet be able to participate in blockchain-based supply chain management systems due to the high degree of digitization and automation required. Because without their participation, it is quite difficult to realize the full potential of blockchain technology in the supply chains to promote the circular economy.

As for the practical implications, this is the first study to address the application of blockchain technology in supply chain management to promote the circular economy. This study has made it possible to understand the possibilities and opportunities blockchain technology can offer in supply chain management to promote the transition to a circular economy. In addition, this study could inspire various supply chain stakeholders to take collective action to gain more insight into supply chain processes.

The focus of this study was mainly on the possibilities and opportunities of blockchain technology in supply chain management to promote the circular economy. However, further research is required on the determinants of organizational acceptance and adoption barriers of blockchain technology in supply chain management. In addition, this study emphasized that more research needs to be done on the strategic motives needed to stimulate the reverse logistics process in supply chains.

References

Alves, L., Ferreira Cruz, E., Lopes, S. I., Faria, P. M., & Rosado da Cruz, A. M. (2021). Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: A review. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *40*(1), 3-23. https://doi.org/10.1177/0734242x211052858

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews*, *100*, 143-174. https://doi.org/10.1016/j.rser.2018.10.014

Baumbusch, J. (2010). Semi-structured interviewing in practice-close research. *Journal for Specialists in Pediatric Nursing*, *15*(3), 255-258. https://doi.org/10.1111/j.1744-6155.2010.00243.x

Böckel, A., Nuzum, A., & Weissbrod, I. (2021). Blockchain for the circular economy: Analysis of the research-practice gap. *Sustainable Production and Consumption*, *25*, 525-539. https://doi.org/10.1016/j.spc.2020.12.006

Böhmecke-Schwafert, M., Wehinger, M., & Teigland, R. (2022). Blockchain for the circular economy: Theorizing blockchain's role in the transition to a circular economy through an empirical investigation. *Business Strategy and the Environment*, 1-16. https://doi.org/10.1002/bse.3032

Caldarelli, G., Zardini, A., & Rossignoli, C. (2021). Blockchain adoption in the fashion sustainable supply chain: Pragmatically addressing barriers. *Journal of Organizational Change Management*, *34*(2), 507-524. https://doi.org/10.1108/jocm-09-2020-0299

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, *38*(5), 360-387. https://doi.org/10.1108/09600030810882816

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics*, *36*, 55-81. https://doi.org/10.1016/j.tele.2018.11.006

CDC. (2019). *Escherichia coli O26 infections linked to Chipotle Mexican Grill restaurants (Final update)*. Centers for Disease Control and Prevention. https://www.cdc.gov/ecoli/2015/o26-11-15/index.html

Chang, Y., Iakovou, E., & Shi, W. (2019). Blockchain in global supply chains and cross border trade: A critical synthesis of the state-of-the-art, challenges and opportunities. *International Journal of Production Research*, *58*(7), 2082-2099. https://doi.org/10.1080/00207543.2019.1651946

Clifford, N., French, S., & Valentine, G. (2010). *Key methods in geography*. SAGE.

De Angelis, R., Howard, M., & Miemczyk, J. (2018). Supply chain management and the circular economy: Towards the circular supply chain. *Production Planning & Control*, *29*(6), 425-437. https://doi.org/10.1080/09537287.2018.1449244

Dubois, A., & Gadde, L. (2002). Systematic combining: An abductive approach to case research. *Journal of Business Research*, *55*(7), 553-560. https://doi.org/10.1016/s0148-2963(00)00195-8

Farooque M., Zhang A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review,. *Journal of Cleaner Production*, *228*, 882-900. https://doi.org/10.1016/j.jclepro.2019.04.303

Flint, D. J. (2004). Strategic marketing in global supply chains: Four challenges. *Industrial Marketing Management*, *33*(1), 45-50. https://doi.org/10.1016/j.indmarman.2003.08.009

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The circular economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational Research Methods*, *16*(1), 15-31. https://doi.org/10.1177/1094428112452151

Grecuccio, J., Giusto, E., Fiori, F., & Rebaudengo, M. (2020). Combining blockchain and IoT: Food-chain traceability and beyond. *Energies*, *13*(15), 3820. https://doi.org/10.3390/en13153820

Haber, S., & Stornetta, W. S. (1991). How to time-stamp a digital document. *Journal of Cryptology*, *3*(2), 99-111. https://doi.org/10.1007/bf00196791

Hussain, M., & Malik, M. (2020). Organizational enablers for circular economy in the context of sustainable supply chain management. *Journal of Cleaner Production*, *256*, 120375. https://doi.org/10.1016/j.jclepro.2020.120375

Ivanov, D., Dolgui, A., & Sokolov, B. (2018). The impact of digital technology and industry 4.0 on the ripple effect and supply chain risk analytics. *International Journal of Production Research*, *57*(3), 829-846. https://doi.org/10.1080/00207543.2018.1488086

J. Rockström, W. Steffen, K. Noone, A. Persson, F.S. Chapin, E.F. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. Wit, T. De Hughes, S. Van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, … M. Falkenmark. (2009). A safe operating space for humanity. *Nature*, *461*, 472-475. https://doi.org/10.1038/461472a

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kouhizadeh, M., Zhu, Q., & Sarkis, J. (2019). Blockchain and the circular economy: Potential tensions and critical reflections from practice. *Production Planning & Control*, *31*(11-12), 950-966. https://doi.org/10.1080/09537287.2019.1695925

Kshetri, N. (2018). Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*, 80-89. https://doi.org/10.1016/j.ijinfomgt.2017.12.005

Kshetri, N. (2021). Blockchain and sustainable supply chain management in developing countries. *International Journal of Information Management*, *60*, 102376. https://doi.org/10.1016/j.ijinfomgt.2021.102376

Lama, D. (1990). Universal Responsibility and the Good Heart. In *In Freedom in Exile: The autobiography of His Holiness the Dalai Lama of Tibet* (pp. 280-299). Hodder and Stoughton.

Lambert, S. D., & Loiselle, C. G. (2008). Combining individual interviews and focus groups to enhance data richness. *Journal of Advanced Nursing*, *62*(2), 228-237. https://doi.org/10.1111/j.1365-2648.2007.04559.x

Loiseau, E., Saikku, L., Antikainen, R., Droste, N., Hansjürgens, B., Pitkänen, K., Leskinen, P., Kuikman, P., & Thomsen, M. (2016). Green economy and related concepts: An overview. *Journal of Cleaner Production*, *139*, 361-371. https://doi.org/10.1016/j.jclepro.2016.08.024

Lopes de Sousa Jabbour, A. B., Jabbour, C. J., Godinho Filho, M., & Roubaud, D. (2018). Industry 4.0 and the circular economy: A proposed research agenda and original roadmap for sustainable operations. *Annals of Operations Research*, *270*(1-2), 273-286. https://doi.org/10.1007/s10479-018-2772-8

Lumineau F., Wang W., & Schilke O. (2021). Blockchain governance—A new way of organizing collaborations? *Organization Science*, *32*(2), 500-521. https://doi.org/10.1287/orsc.2020.1379

Luthra, S., Kumar, A., Zavadskas, E. K., Mangla, S. K., & Garza-Reyes, J. A. (2019). Industry 4.0 as an enabler of sustainability diffusion in supply chain: An analysis of influential strength of drivers in an emerging economy. *International Journal of Production Research*, *58*(5), 1505-1521. https://doi.org/10.1080/00207543.2019.1660828

MacArthur E., Zumwinkel, K., & Stuchtey, M. R. (2015). *Growth within: a circular economy vision for a competitive Europe*. Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org/growth-within-a-circular-economy-vision-for-a-competitive-europe

McKinsey & Company. (2016). *Sustainability & Resource Productivity*. http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/mckinsey-on-sustainability-and-resource-productivity/mckinsey-on-sustainability-and-resource-productivity-number-4

Morabito, V. (2017). *Business Innovation Through Blockchain: The B3 Perspective*. Springer.

Nakamoto S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. https://bitcoin.org/bitcoin.pdf

Ryan, F., Coughlan, M., & Cronin, P. (2009). Interviewing in qualitative research: The one-to-one interview. *International Journal of Therapy and Rehabilitation*, *16*(6), 309-314. https://doi.org/10.12968/ijtr.2009.16.6.42433

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2018). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117-2135. https://doi.org/10.1080/00207543.2018.1533261

Saunders M., Lewis P., & Thornhill A. (2012). *Research Methods for Business Students* (6th ed.). Pearson Education Limited.

Timmermans, S., & Tavory, I. (2012). Theory construction in qualitative research. *Sociological Theory*, *30*(3), 167-186. https://doi.org/10.1177/0735275112457914

UN. (2022). *Sustainable consumption and production*. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/sustainable-consumption-production/

Upadhyay, A., Mukhuty, S., Kumar, V., & Kazancoglu, Y. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of Cleaner Production*, *293*, 126130. https://doi.org/10.1016/j.jclepro.2021.126130

Wang, B., Luo, W., Zhang, A., Tian, Z., & Li, Z. (2020). Blockchain-enabled circular supply chain management: A system architecture for fast fashion. *Computers in Industry*, *123*, 103324. https://doi.org/10.1016/j.compind.2020.103324

Yildizbasi, A. (2021). Blockchain and renewable energy: Integration challenges in circular economy era. *Renewable Energy*, *176*, 183-197. https://doi.org/10.1016/j.renene.2021.05.053

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where is current research on blockchain technology?—A systematic review. *PLOS ONE*, *11*(10), e0163477. https://doi.org/10.1371/journal.pone.0163477

Appendix A: Interview Guide

First, let me introduce myself: My name is Roel van Klaveren, and I am following a bachelor's degree in Global Responsibility and Leadership at the University of Groningen | Campus Friesland. For my thesis, I am researching how blockchain technology can be used to improve supply chain management toward a circular economy.

The Fourth Industrial Revolution is seen as a complete transformation of our society: merging the physical, digital, and biological worlds. While the fourth industrial revolution has changed the way we produce and offers opportunities to change our lives, this transformation also highlights the need to consider creating a more environmentally sustainable society. Therefore, a circular economy can offer new opportunities for sustainable development by reducing waste and reusing, recycling, and recovering materials in production, distribution, and consumption processes. However, to realistically implement a circular economy, systems with basic competencies such as security, transparency, traceability, and provability are needed.

Formalities

- I would like to emphasize that all your personal information will be treated confidentially, and you can leave the interview at any time. If you’re not comfortable answering a question, let me know so we can move on with further questions.
- Do you give permission to make audio and video recordings? If not, you can indicate that you do not agree, and I will take notes during the interview.

Introduction Questions

1. Could you introduce yourself and what your current work is?

2. What is your experience and involvement with blockchain technology, supply chain (management), and circularity?

Integration of Blockchain Technology

Industry 4.0 technologies such as artificial intelligence and the “Internet of Things” can connect the real world with the digital world. Industry 4.0 technologies could collect data during all product life cycle phases.

3. What is the added value of Industry 4.0 technologies in supply chain management?
    a. Pre-production phase (*probes:* stock, logistics, selection of suppliers)
    b. Production phase (*probes:* environmental impact)
    c. Post-production phase (*probes:* distribution processes)

4. Traditionally, collected data is transferred to cloud databases. How is collected data transferred by IoT technologies to a blockchain network?
    a. When will data be transferred to the blockchain network?
    b. Does the collected data need to be preprocessed before being added to the blockchain network?

5. How is data stored on the blockchain network?
    a. Is the data stored on the blockchain, or are there generated hash values stored in the blockchain network?

The functionality of Blockchain Technology

Supply chain management

The literature describes that supply chain management faces common challenges such as traceability, transparency, reliability, and stakeholder collaboration. It is mentioned that blockchain technology offers a unique opportunity to record collected data and information in real-time.

6. How would you rate the presence of the following aspects within traditional supply chain management?
    a. Traceability
    b. Transparency
    c. Reliability
    d. Stakeholder collaboration

7. How can blockchain technology determine the production environment and processes (e.g., safety requirements) in real-time in production activities?

8. What flexibility benefits does blockchain technology offer for supply chain management?

9. What practical applications of blockchain technology within supply chain management have you already observed?

10. Implementing smart contracts is one of the most transformative uses of blockchain technology. What is the added value of smart contracts in supply chain management?
    a. Some blockchain experts suggest that the functionality of smart contracts depends on how it is written. To what extent do you agree/disagree with this statement?

Circular economy

CE processes such as remanufacturing and dismantling of products can be very complicated as the condition of used products can vary greatly, requiring products to be discarded after retrieval if they are irreparably damaged.

11. How can a blockchain-based system ensure that manufacturers can verify and authenticate which materials can be reused at the end of their life and which should be disposed of?

A radical shift towards a circular economy within supply chain management is not easy to implement as product recycling is rarely seen as a value-creating system until now.

12. To what extent do you agree with this perception of value creation?
    a. Do you have any examples that confirm this traditional perception of value creation? Why do you think that many people still do not see the concept of a circular economy as a value-creating system?
    b. Have you noticed a shift in this perception?

Sustainability assessment management is essential for incorporating circular economy principles into supply chain management. Businesses are not only assessed on their business qualifications, but also on their responsibilities for sustainability.

13. How can blockchain technology contribute to evaluating and selecting sustainable supply chain stakeholders?

Unlike a linear supply chain, where the end-of-life products go to a landfill, reverse logistics is an integral part of a circular supply chain to return end-of-life products to upstream players in the supply *chain for reuse and value recovery. However, even though reverse logistics systems have been put into practice since the early 20th century, there is still a lack of strategic rationale to integrate the concept of supply chains with closed material and energy cycles.*

14. What strategic motives do you think are necessary to integrate reverse logistics systems into supply chains with closed material and energy cycles?

Considerations

The type of blockchain and the following rights are crucial to its application and context. It influences the access to, and modification of the information on the blockchain that determines the degree of centrality and transparency.

15. In which scenarios for supply chain management is it more favourable to use an open blockchain?

16. In which scenarios for supply chain management is it more favourable to use a closed blockchain?

17. What limitations have you observed in practice using blockchain technology for supply chain management?

18. To what extent do you think companies are willing to invest in a technology that is not yet fully mature?

Closing Questions

19. Are there any other essential things about blockchain technology, supply chain management, or a circular economy that I didn't ask you about?

20. Do you have any questions yourself?

21. Would you like to receive the thesis results after it has been submitted to the university?

Thank you for taking the time to answer all my questions. I can assure you that this has helped me enormously with my thesis research. Please feel free to contact me if you want to make additional comments, ask questions, or raise concerns. I wish you a nice day!

Note: The grey text indicates interview questions that were not covered in all semi-structured interviews.

Appendix B: Participant Consent Form

Participant consent form to partake in research conducted by Roel van Klaveren for graduation thesis in the BSc Global Responsibility and Leadership program at the University of Groningen, Campus Fryslân.

Research Title: Towards a Circular Economy: Integrating Blockchain Technology into Supply Chain Management

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Thank you for agreeing to get interviewed as a part of the thesis research project. Ethical procedures for academic research from the University of Groningen require that participants provide explicit consent to participate in research and are cognizant of how their information and information given in their interviews will get treated. This consent form is important for the researcher to ensure that you understand the purpose of your involvement and agree to the conditions of your participation. Therefore, it is kindly asked of you to read the accompanying provisions and then sign this form at the end to attest your approval of your participation conditions:

- I ________________________, give a voluntary agreement to participate in this research.
- I understand that, after having signed this document, I have the right to withdraw from the research at any point in time or refuse to answer any question without any consequences. I am aware that I can leave out the reasons for withdrawal and refusal to answer questions.
- I understand that I can withdraw permission to use data from my interview within two weeks after the interview. After withdrawal, all materials related to my interview will get deleted.
- I understand that I will get asked before the interview begins whether I agree to be audio and video-recorded, with a transcript produced. I have the freedom to wish not to get recorded. Consequently, the interviewer will take notes of the interview instead of recording it.
- I understand that participation involves getting interviewed for approximately one hour. The interview will be an in-depth semi-structured interview regarding integrating blockchain technology into supply chain management toward a circular economy.
- I understand that I have been asked to participate in sharing my experience within the context of blockchain technology, supply chain management, and the circular economy.
- The researcher will analyze the interview transcript as a part of the research.
- I understand that I will not get direct benefits from participating in this research, such as financial rewards. The information obtained from my interview may contribute to further knowledge on research topics and be informative for future research.
- I understand that the study intends to include other participants.
- I understand that all information I provide for this study will get treated confidentially.
- I understand that my identity will appear anonymous throughout the research report. That will be ensured by having my name removed, using a participant number instead and disguising any details disclosing my identity and the identity of individuals I may mention from my interview.

- I understand that the researcher will use the information given in this interview for this research, and excerpts from my interview may get quoted in the thesis research paper.

- I understand that the study results will be used within the scope of the thesis research.

- I understand that the signed consent form and the original audio/video recordings will get retained in the Google Drive storage platform. Only the Researcher, Roel van Klaveren, will have access to these documents and will not share or expose them to any individual except the interviewee on request. All interview recordings will get deleted after the thesis submission on 10.06.2022.

- I understand that the freedom of information legislation entitles me to access all information I have provided at any time while it is in storage in Google Drive, as specified above.

- I understand that data (consent forms, recordings, interview transcripts) will be retained on the Y-drive of the University of Groningen server for five years, in correspondence with the university AVG legislation.

- I have had the purpose and nature of the study explained to me in writing, and I have had the opportunity to ask questions about the research.

- Any variation of conditions set above will occur only with the participant's explicit approval.

- I understand that the researcher will uphold themselves to relevant ethical standards.

- I have read the information sheet and was able to ask any additional question to the Researcher.

- I understand I may ask questions about the study at any time.

[please see next page]

I wish to receive a copy of the scientific output of the project: yes / no

I consent to be re-contacted for participating in future studies: yes / no

Having read and understood all the above, I agree to participate in the research: yes / no

Research participant giving informed consent to take part in research, having the ability to withdraw from research at any point in time:

______________________________ ______________________ __________________

Participant Full Name Signature Date

To be filled in by the researcher:

- o I declare that I have thoroughly informed the research participant about the research study and answered any remaining questions to the best of my knowledge.
- o I agree that this person participates in the research study.

Signature of researcher Roel van Klaveren, granting respect and compliance with the provisions with respect to the participant, as signed and identified above:

______________________________ ______________________ __________________

Researcher Full Name Signature Date