Innovative Solution: Unveiling the Role of Blockchain Technology in Green Supply Chain Management - Expert Insights

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Abstract

Title: Innovative solution: Unveiling the role of blockchain technology in green supply chain management – expert insights

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This thesis examines the potential of blockchain technology (BCT) in green supply chain management (GSCM) and how it can be implemented. It investigates the capabilities of BCT to overcome existing barriers in GSCM and improve its environmental performance (EP), thereby closing the current research gap.

A qualitative research method was used to answer the research question (RQ). Thirteen semi-structured expert interviews were conducted and analyzed using Kuckartz's content structuring method to gain deep insights into the potential of BCT in GSCM.

The results of the qualitative research shed new light on the drivers and barriers of GSCM identified in the literature. Additionally, the findings highlight the potential of BCT in GSCM as an enabler to overcome GSCM barriers, particularly in enhancing trust, fostering collaboration and improving data transparency between supply chain (SC) participants. This facilitates more efficient implementation and monitoring of environmental initiatives throughout the SC and ultimately leads to a positive EP.

Furthermore, the findings of this thesis provide practical insights for companies interested in integrating BCT into their GSCM practices. It offers guidance on how to design the blockchain architecture. Additionally, this thesis gives an overview of the necessary technological and organizational requirements for a successful implementation. Finally, it addresses critical aspects of BCT, such as energy consumption and vulnerability to data manipulation, to provide clarity on these concerns.

Keywords: blockchain technology; potential of blockchain technology; implementation of blockchain technology; green supply chain management; environmental performance; expert interviews

Abstrato

Título: Solução inovadora: Revelar o papel da tecnologia de cadeias de blocos na gestão da cadeia de abastecimento ecológica - opiniões de especialistas

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Esta tese explora o potencial da tecnologia blockchain para a gestão da cadeia de abastecimento verde e sua implementação. Aborda a lacuna de investigação sobre a aplicação do blockchain na gestão sustentável da cadeia de suprimentos, investigando sua capacidade de superar barreiras existentes e melhorar o desempenho ambiental.

Para responder à questão de investigação, foi utilizada uma metodologia qualitativa, com treze entrevistas semi-estruturadas com especialistas. Estas entrevistas foram analisadas com o método de estruturação de conteúdos de Kuckartz para obter insights sobre o potencial do blockchain na gestão sustentável da cadeia de suprimentos.

Os resultados da investigação lançam nova luz sobre os fatores impulsionadores e barreiras da gestão sustentável da cadeia de suprimentos identificados na literatura. Além disso, destacam o potencial do blockchain como facilitador na superação dessas barreiras, especialmente no aumento da confiança, promoção da colaboração e melhoria da transparência de dados entre os participantes da cadeia de suprimentos. Isso facilita uma implementação e monitoramento mais eficientes das iniciativas ambientais, levando a um desempenho ambiental positivo.

A tese oferece informações práticas para empresas interessadas em integrar o blockchain em suas práticas de gestão sustentável da cadeia de suprimentos, incluindo orientações sobre a concepção da arquitetura blockchain e os pré-requisitos tecnológicos e organizacionais necessários para uma adoção bem-sucedida. As críticas ao blockchain, como seu consumo de energia e a suscetibilidade à manipulação de dados, são abordadas, proporcionando clareza sobre essas preocupações.

Palavras chave: tecnologia de blockchain; potencial da tecnologia de blockchain; implementação da tecnologia de blockchain; gestão ecológica da cadeia de abastecimento; desempenho ambiental; entrevistas com peritos

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List of Abbreviations

SCM	Supply Chain Management
SSCM	Sustainable Supply Chain Management
SC	Supply Chain
GSCM	Green Supply Chain Management
EP	Environmental Performance
BCT	Blockchain Technology
RQ	Research Question

Chapter 1: Introduction

In recent years, the pressure on companies´ supply chain management (SCM) has increased enormously. Trends such as globalization, shorter product life cycles and digitalization meet developments such as scarcity of resources and tighter regulation by legislators resulting in SCM becoming increasingly complex. Both consumers and governments increasingly expect companies to consider sustainable measures as part of their SCM (Pagell & Shevchenko, 2014; Saeed & Kersten, 2019). To meet these expectations, the sub-area of sustainable supply chain management (SSCM) has developed within SCM. SSCM addresses "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring & Müller, 2008, p.1700).

In particular, the supply chain (SC) of companies can have a major impact on the environment, as a study by McKinsey & Company (2016) reveals. This study indicates that over 80 percent of companies' greenhouse gas emissions and over 90 percent of their impact on air, land, water, biodiversity and geological resources are attributable to their SCs. Taking this into account and the fact that it would go beyond the scope of this thesis to consider all three dimensions, this thesis therefore concentrates on the environmental aspect.

So the question arises how can companies improve their environmental performance (EP) in their SCM? In the literature, many different approaches and studies are described in the context of so-called Green Supply Chain Management (GSCM) (Tseng et al., 2019). Among other aspects, the literature repeatedly indicates that digital technologies can play a key role in achieving a GSCM. While digital technologies such as the Internet of Things or big data analytics are becoming increasingly common in SCM, the use of blockchain technology (BCT) is still an absolute rarity (Stroumpoulis & Kopanaki, 2022).

Initial research findings in the literature indicate that BCT, with its unique characteristics, can offer numerous potential benefits for SCM (Cole et al., 2019). First pilot projects in companies also suggest that BCT has great potential in SCM and especially in GSCM. For example, the food retailer Carrefour Group has launched a test project in collaboration with IBM that enables end consumers to track the product life cycle using a QR code on organic products. Such transparency is made possible by an underlying BCT (Carrefour Group, 2022).

Despite the first promising pilot projects on this topic, there is still a large research gap in the literature in terms of studies investigating the potential of BCT in GSCM (Khanfar et al., 2021). In particular, there is a lack of studies that not only approach this topic on a theoretical level but also substantiate the results with qualitative evidence from practice (Arshad et al., 2023; Esmaeilian et al., 2020). For this reason, this thesis addresses this gap by the following research question (RQ).

RQ: What potential does blockchain technology have in green supply chain management and how can it be implemented?

To answer this question, a qualitative research methodology is used in this thesis due to the novelty and multiple perspectives on this topic. The thesis is structured as follows: *Chapter two* provides a systematic literature review to examine the current state of research on GSCM and BCT. *Chapter three* outlines the methodology, providing details of the approach used to answer the RQ, the methodology of primary data collection and the data analysis method chosen. In *chapter four*, the results obtained from the interviews are presented and analyzed in six main categories. *Chapter five* discusses the theoretical and practical contributions of this thesis, answers the RQ and provides an overview of the limitations and directions for future research. *Chapter six* concludes the thesis by summarizing the main findings on the potential of BCT in GSCM.

In summary, this thesis aims to improve the academic understanding of the role of BCT in GSCM and to provide practical insights for companies seeking to integrate BCT into their GSCM practices. The findings provide a framework for leveraging the potential of BCT in GSCM and offer guidelines for its implementation.

Chapter 2: Literature Review

The following literature review examines the current state of research in the field of SCM, particularly with a focus on GSCM, and the current application of BCT in this area. To provide a comprehensive understanding, the first subsection of the literature review explains the basic concepts of SCM. The next subsection gives an overview of GSCM. The third subsection delves into BCT in general. Finally, the literature review concludes with a section exploring the application of BCT in SCM.

2.1. Basics around Supply Chains

To create a common understanding of terminology for the upcoming literature review and subsequent qualitative research, it is important to define the terms "supply chain" and "supply chain management" precisely.

2.1.1. Definition Supply Chain

The term SC is a widely used concept and several academics have already defined it, as Mentzer et al. (2001) illustrate in their research. La Monde and Masters (1994) describe a SC as a process used to manufacture and place products. This process involves several independent companies, such as manufacturers of raw materials and components, product assemblers, wholesale distributors and retailers. Christopher (1992) describes a SC rather as a network consisting of many participating organizations that are linked together by various activities and processes and work together to produce value for end consumers in the form of products and services. Network because several suppliers and customers are typically involved in the production process. Given the availability of definitions, this thesis refers to the definition by Mentzer et al. (2001) and therefore defines SC "as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer" (p.4).

2.1.2. Definition Supply Chain Management

As Lambert et al. (1998) explain, the term SCM was first used by a consultant in the early 1980s. Since then, there have been numerous attempts in the literature to define and structure this term. Until 1998, the terms SCM and logistics were often used synonymously and SCM was only regarded as logistics outside the company. Since 1998, the Council of Logistic Management has defined that logistics is only a part of SCM (Lambert et al., 1998).

Since then, the definition of SCM has evolved significantly to encompass a broader scope that includes all companies involved in the SC, their respective business functions and the coordination of activities within and between them. SCM crosses departmental boundaries and encompasses the collaboration of different business functions such as research and development, production, procurement, logistics, marketing, sales, finance and customer service. Its main objective is to manage the flow of goods, services, financial resources and related information across the entire SC, from the supplier to the end customer (Mentzer et al., 2001).

Building on this development of the term, Mentzer et al. (2001) therefore define SCM as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular firm and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual firms and the supply chain as a whole" (p.18). As this is the most used definition of SCM in recent literature, this thesis also follows the same definition.

2.2. Green Supply Chain Management

The inclusion of environmental aspects in SCM has evolved into a distinct research area within SSCM, known as GSCM (Sarkis, 2012). As mentioned in the introduction, companies' SCs are responsible for up to 90 percent of their emissions and their impact on the environment (McKinsey & Company, 2016). For this reason, companies try to minimize the negative impact of their SCM on the environment as much as possible to improve their EP (Tseng et al., 2019). To achieve this goal, the literature refers to the concept of GSCM, which is explained in the following subchapter. Followed by the impact of GSCM on EP as well as the drivers and barriers of GSCM. Figure 1 gives an overview of the relationships between the individual components of GSCM, which are presented in the following subchapters.

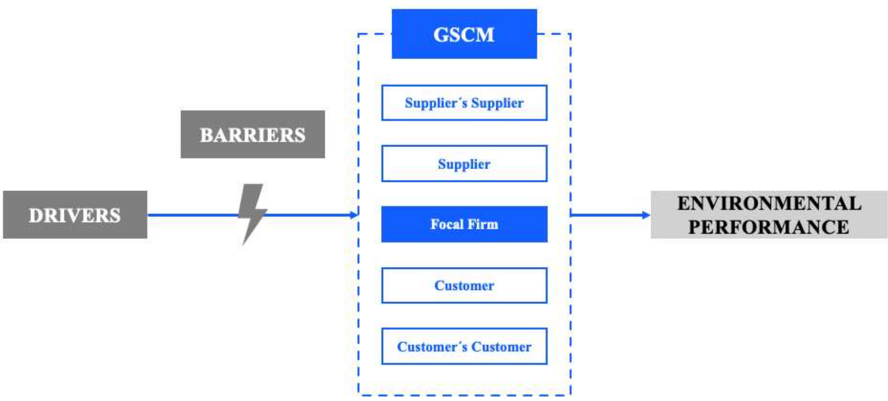

Figure 1: Framework GSCM (Source: Own illustration based on Mentzer et al., 2001; Tseng et al., 2019)

2.2.1. Concept of Green Supply Chain Management

Historically, the study and control of industrial pollution have been a major social concern since the industrial revolution. Back then, the focus was on improving operational efficiency and minimizing waste. The reason for this were not environmental concerns, but purely economic cost reasons (Dubey et al., 2019; Yakovleva et al., 2012). The concept of GSCM emerged in the literature after the 1990s, evolving from traditional SCM practices (Khan et al., 2023; Seuring & Müller, 2008).

Like the SCM concept, there is no standard definition or approach to the GSCM concept (Zhu and Sarkis 2004). However, there is general agreement in the literature that GSCM is about "integrating environmental concerns into the inter-organizational practices of SCM including reverse logistics" (Sarkis et al., 2011, p.3). This includes product design, material sourcing and selection, the manufacturing and delivery process of the final product and the end-of-life management of the product (Srivastava, 2007).

This understanding of the term GSCM indicates that throughout SCs there are a variety of different green practices that a company can pursue. These are "ranging from green design (marketing and engineering), green procurement practices (e.g. certifying suppliers, purchasing environmentally sound materials/products), total quality environmental management (internal performance measurement, pollution prevention), environmentally friendly packaging and transportation, to the various product end-of-life practices" (Hervani et al., 2005, p.334). All these practices are summarized in the literature under the term "Re's", representing reduction, reuse, reprocessing and recycling (Al-Ghwayeen & Abdallah, 2018; Hervani et al., 2005). GSCM practices are therefore various management activities designed to integrate environmental concerns into SCM to improve EP along the entire SC (Lee, 2015).

2.2.2. Green Supply Chain Management and Environmental Performance

Numerous studies in the literature confirm the effectiveness of adopting a GSCM in enhancing the EP of companies (Ahmad et al., 2022; Chin et al., 2015; Schrettle et al., 2014). In this context, the literature defines the term EP, "as the outcome of a company's strategic activities that manage (or not) its impact on the natural environment“ (Walls et al., 2012, p.891).

However, measuring the EP of companies is a complex process, as there are no standard metrics for EP (Al-Ghwayeen & Abdallah, 2018). For instance, Yakovleva et al. (2012) cite energy and water consumption as well as waste arising as the main indicators in their paper. Dubey et al.

(2019) highlight five indicators in their paper, namely the reduction of solid and liquid waste, the reduction of atmospheric emissions, the limited consumption of resources and hazardous or toxic materials, and the environmental image of a company. As a result, there are major differences between companies regarding which key performance indicators they use to measure their EP (Al-Ghwayeen & Abdallah, 2018).

2.2.3. Drivers of Green Supply Chain Management

After describing the concept of GSCM and its relationship with EP, the next step is to understand the underlying drivers. In this context, drivers can be seen as motivators that encourage companies to adapt their actions and take sustainable initiatives (Hoffman, 2001). A variety of different drivers are discussed in the literature, such as governments, competitors, customers, various interest groups and industry associations (Delmas & Toffel, 2004). Although the specific drivers differ between the individual papers depending on the context examined, the majority differentiate between internal and external drivers (Hsu et al., 2013; Jahn et al., 2017; Saeed & Kersten, 2019; Schrettle et al., 2014; Walker et al., 2008; Zimon et al., 2020). According to the literature, external drivers exert greater pressure on companies to adopt a GSCM than internal drivers (Saeed & Kersten, 2019).

(1) External Drivers

External drivers are factors that originate from outside the company but have an influence on the internal actions of companies (Hsu et al., 2013). A variety of different external factors for the introduction of a GSCM have been identified in the literature and categorized as regulatory pressure, social pressure and market pressure (Jahn et al., 2017; Saeed & Kersten, 2019; Schrettle et al., 2014; Walker et al., 2008).

Regulatory pressure refers to official mechanisms of regulatory institutions, such as standards, laws, procedures and incentives, which are intended to encourage companies to act in an environmentally sustainable manner (Hsu et al., 2013). Companies that fail to comply with the relevant regulations face fines and trade barriers. In addition, companies are obliged to comply with the regulations in each country or region in which they operate, although different countries may have different regulations (Saeed & Kersten, 2019).

Societal pressure, also referred to as social norms and values in the literature, are the demands and expectations of interest groups such as non-governmental organizations, media and societal groups (Jahn et al., 2017; Schrettle et al., 2014). This social pressure raises public awareness and focuses attention on the various sustainability issues that companies face, such as their handling of resource scarcity and the impact of their business on the environment (Walker et al., 2008). In particular, when companies have caused negative headlines through their activities, the pressure from stakeholders to improve their environmental sustainability continues to increase (Alblas et al., 2014).

Market pressure describes the market landscape that forms the context in which the respective company is operating (Jahn et al., 2017; Rivera-Camino, 2007; Schrettle et al., 2014). Consumers, suppliers and buyers, competitors, investors and shareholders are the stakeholders responsible for this market pressure (Jahn et al., 2017; Rivera-Camino, 2007; Saeed & Kersten, 2019). Customers, for example, can react positively to companies' sustainability initiatives and thus increase demand for their products (Rivera-Camino, 2007). Equally, however, investors may withdraw their investment from companies if they do not pursue environmental sustainability goals and therefore represent an increased risk for them (Jahn et al., 2017; Schrettle et al., 2014).

(2) Internal Drivers

Internal drivers are the pressures that arise within the company and motivate it to pursue environmentally sustainable behavior (Caniato et al., 2012; Köksal et al., 2017). In literature, these internal drivers are categorized into four groups, namely corporate strategy, organizational culture, organizational resources and organizational characteristics (Jahn et al., 2017; Saeed & Kersten, 2019; Schrettle et al., 2014; Walker et al., 2008).

The integration of environmental sustainability goals into the ***corporate strategy*** is essential for achieving the goals within the GSCM and requires the corresponding internal support. For the corporate strategy, the commitment of top management to environmental sustainability is essential. Additionally, the sustainability strategy must be integrated throughout the entire company. Cost-related drivers and operational performance also motivate the adoption of GSCM, as environmental sustainability goals like reduced energy or material consumption can lower costs (Jahn et al., 2017; Saeed & Kersten, 2019).

Organizational culture significantly influences companies and their motivation to pursue environmental sustainability goals (Jahn et al., 2017). The main drivers include management commitment, information sharing and exchanging, and a long-term planning horizon (Schrettle et al., 2014).

Organizational resources and access to these are crucial internal drivers for achieving a GSCM (Schrettle et al., 2014). These resources include physical capital, such as new technologies and equipment for sustainable innovation capability. Additionally, they encompass human capital, which involves existing skills and knowledge for GSCM, and the ability to engage all employees in the company (Jahn et al., 2017; Saeed & Kersten, 2019).

Organizational characteristics are the final internal driver of GSCM. Factors such as industry sector, geographic location, and company size influence stakeholders' perceptions of expected environmental sustainability practices (Jahn et al., 2017; Saeed & Kersten, 2019). For instance, larger companies often face more significant environmental challenges than smaller ones and, as a result, experience greater pressure from stakeholders (Haverkamp et al., 2010).

2.2.4. Barriers of Green Supply Chain Management

Besides the drivers, the literature also mentions several barriers associated with the introduction of GSCM. Companies need to identify these barriers to deal with them in the best possible way. As with the drivers, the literature again identifies a variety of different barriers, which are sorted into different categories. However, most papers distinguish between five different categories (Govindan et al., 2014; Jianguo & Solangi, 2023; Scur & Barbosa, 2017). According to the literature, the technological barriers have the greatest weighting, followed by the outsourcing barriers and the financial barriers (Govindan et al., 2014).

(1) Outsourcing Barriers

Outsourcing is about the challenges that arise when delegating tasks in the supply chain to external parties while maintaining environmental sustainability (Govindan et al., 2014). First, there is a complexity in measuring and monitoring suppliers' environmentally sustainable practices. In particular, there is a lack of standardization of measurement methods along the SC stakeholders, which leads to inefficiencies in their coordination (Wang et al., 2016). At the same time, it is also a challenge to maintain environmental awareness among individual suppliers and to keep up the relationship with environmentally conscious suppliers (Mathiyazhagan et al., 2013). In addition, there is a lack of governmental support for the adoption of environmentally sustainable practices. However, regulations are an important instrument to encourage companies to introduce environmentally sustainable practices (Zhu et al., 2012).

(2) Technological Barriers

For the successful adoption of a GSCM, it is also important to consider new trends and the use of technology. However, most companies lack the technology and processes to drive the implementation of a GSCM. In addition, there is a lack of human resources and technical expertise to understand how to utilize technology (Govindan et al., 2014). At the same time, it is also a challenge for many companies to design products in such a way that they can be reused and recycled (Mangla et al., 2017). Finally, there are concerns about a possible failure of the technology, which could harm the company's financial and strategic position (Jianguo & Solangi, 2023).

(3) Information and Knowledge Barriers

There are often various knowledge gaps and a lack of awareness that prevent companies from adopting green practices. On the one hand, there is a lack of knowledge about the environmental benefits associated with the introduction of GSCM. On the other hand, there is a lack of understanding of GSCM strategies such as reverse logistics, which is key to reducing waste and maximizing profits. The complexity of the process of collecting used products for recycling and reuse is also a challenge (Govindan et al., 2014; Mangla et al., 2017).

(4) Financial Barriers

Often the implementation of GSCM practices is also hindered by a lack of financial support (Zhang et al., 2009). The introduction of environmental practices is usually associated with high investment costs, which some companies do not want to or cannot afford. At the same time, there is often a lack of support from banks, for example in the form of loans to finance such projects (Moktadir et al., 2018).

(5) Managerial Barriers

The introduction of GSCM depends largely on management involvement and support. However, the lack of management commitment is often a barrier to transforming existing processes into more environmentally friendly ones. There is also a lack of concrete plans for the implementation of environmental initiatives in SCM. Without clearly defined environmental goals from the management level, effective implementation is not possible (Jianguo & Solangi, 2023). There is also a lack of appropriate training and consultancy programs to accompany the progress within an industry (Govindan et al., 2014).

2.3. Blockchain Technology

BCT is one of the many different technologies that can be summarized under the term Industry 4.0. Industry 4.0 includes technologies such as cloud computing, the Internet of Things, big data analytics, artificial intelligence, and cyber-physical systems (Qader et al., 2022). This term describes the fourth industrial revolution, characterized by the digitalization of production. Building on the third industrial revolution, which introduced computers and automation, Industry 4.0 expands on these advancements with intelligent and autonomous systems (Marr, 2018). Industry 4.0 is an approach that enables more efficient control of production processes by synchronizing them in real time and allowing the manufacture of both standardized and customized products (Moeuf et al., 2018).

Since it is beyond the scope of this thesis to examine all Industry 4.0 technologies, this thesis focuses on BCT. To better understand the potential of BCT in GSCM, this chapter explains the general functioning of BCT and its characteristics based on the literature.

2.3.1. General Functioning of Blockchain Technology

BCT first gained recognition as a platform for managing digital cryptocurrency, in particular Bitcoin (Nakamoto, 2008). However, nowadays it is known that the possible application areas for BCT are far broader. BCT is a form of distributed public ledger technology, which describes the characteristics of a blockchain quite well (Crosby, 2016; Esmaeilian et al., 2020; Hughes et al., 2019; Saberi et al., 2019).

BCT is a ledger of transactions stored in blocks that are lined up systematically and linearly (Hughes et al., 2019). A block contains all the data of a transaction in an encrypted form. This data can be information such as date, time, location and amount of money, but can also be an image or text. Within a block, all transactions are given the same time stamp. Each block has a unique identity, also known as a hash, which precisely identifies the respective block and its content. In addition, each block within the chain is linked to its previous block (Peres et al., 2023; Risius & Spohrer, 2017).

As previously mentioned, a blockchain is a distributed ledger technology. Distributed because the transactions take place in a distributed peer-to-peer network. Each computer within this network becomes a node, which has a copy of the entire blockchain. Therefore, there is no central node that monitors the uniformity of the ledgers across all distributed nodes. Consequently, alternative mechanisms are required to ensure the consistency of the ledger between nodes and to verify the authenticity of new transactions. These mechanisms, known as consensus mechanisms, play a central role in maintaining the integrity of the BCT (Peres et al., 2023; Zheng et al., 2018). Depending on the type and intended use of the BCT, different consensus mechanisms are used, as illustrated in Table 1.

Property	Public Blockchain	Consortium Blockchain	Private Blockchain
GENERAL			
Definition	Open to everyone	Managed by two or more individuals, companies or business outfits	Controlled by one authority
PERMISSION & CONSENSUS TYPE			
Access Permission	Permissionless	Permissioned	Permissioned
Read Permission	Public	Public or restricted	Public or restricted
Consensus Determination	All miners	Selected set of nodes	One organization
CHARACTERISTICS			
Decentralized	Yes	Partial	No
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Energy	High energy consumption	More environmental	More environmental

Table 1: Comparison among different types of BCT (Source: Own illustration based on Zheng et al., 2018; Zhou et al., 2023)

In general, the literature distinguishes between two main types of BCTs, permissionless and permissioned blockchains, based on the access control mechanism used. The main difference between the two types lies in membership, meaning the ability to participate in the blockchain. A permissionless blockchain is a public network that anyone can join and use for their transactions. Every transaction is public, but the transaction participants can remain anonymous. Bitcoin is probably the best-known example of a permissionless blockchain. In a permissionless blockchain, all nodes can potentially act as miners, meaning that all nodes can participate in the consensus process and thus validate new transactions and add them as blocks. Besides, there are also permissioned blockchains. To participate in a permissioned blockchain, participants must receive permission in advance. In this type of blockchain, access is typically controlled by either a consortium of members (consortium blockchain) or an organization (private blockchain). In a consortium blockchain, a selected group of nodes normally validates the new transactions across the participating organizations. In contrast, in a private blockchain, only a single organization controls which nodes are authorized to validate (Cole et al., 2019; Wang et al., 2019; Zheng et al., 2018).

2.3.2. Characteristics of Blockchain Technology

The functionality of BCT described in 2.3.1. reveals that it differs significantly from most existing and used information systems (Saberi et al., 2019). The literature emphasizes five characteristics in particular: ***decentralization***, ***security***, ***auditability, immutability*** and ***smart execution.*** Depending on the type of blockchain selected, some of the characteristics of the BCT are more or less strong, as Table 1 also shows (Hughes et al., 2019; Saberi et al., 2019; Zheng et al., 2018).

BCT requires neither an intermediary to carry out an interaction nor a large central server to store and manage data. Instead, all information is stored ***decentralized*** on every node in the network (Hughes et al., 2019). Completely decentralized, however, are only public blockchains, whereas consortium and private blockchains are more centralized, as the data is only distributed on the authorized nodes within the respective organizations (Zheng et al., 2017). Compared to traditional databases, this decentralization makes the BCT very robust against crashes or hacker attacks and increases its ***security*** (Feng Tian, 2016; Hughes et al., 2019). In addition to the security of the data, BCT also leads to an increased ***auditability*** of the data and consequently to an increased trust of the participants. This is because the elimination of the need for an intermediary to carry out transactions also eliminates the need for trust in this intermediary and the other participants. It is sufficient if all participants trust the BCT itself (Nofer et al., 2017; Saberi et al., 2019). Another important characteristic of BCT is its ***immutability***. As described above, the individual transactions are stored across all nodes, making it almost impossible to manipulate them retrospectively. A public blockchain is particularly difficult to manipulate due to its strong decentralization. A consortium or private blockchain would be relatively easier to manipulate, as the corresponding number of nodes required for tampering would be reached more quickly (Zheng et al., 2017). Besides encouraging trust and transparency, the literature often mentions BCT's ability for ***smart execution***. BCT offers the opportunity to automatically verify and execute transactions using so-called smart contracts, based on the predetermined conditions and measures (Delmolino et al., 2016; Saberi et al., 2019).

2.4. Blockchain Technology in Supply Chain Management

Having explained BCT as such and examined what special characteristics it has from the perspective of the literature; the following section explores what applications BCT can have in SCM. Although BCT was initially recognized mainly for its role in supporting cryptocurrencies, its potential applications extend far beyond this realm. Recently, there has been a growing discussion in the literature about the potential applicability of BCT in supply chain management (Hughes et al., 2019). To understand how BCT can be used to support SCM, the following subchapter outlines the potential benefits and criticisms of using this technology based on the literature.

2.4.1. Potential Benefits of Blockchain Technology in Supply Chain Management

BCT enables the tracking of various product metrics along the SC, including product type, quality, quantity, current location, and ownership. This information can be securely stored within the blockchain (Saberi et al., 2019).

Furthermore, Cole (2019) illustrates that some of the characteristics described in 2.3.2. also have benefits and applicability for SCM. For example, the decentralized ledger can serve as a unified data source to provide a transparent audit trail and ensure consistent manufacturing, assembly, delivery and maintenance processes between the various stakeholders. Manufacturers can also improve product traceability and identify problems with specific products, components or material sources more quickly. BCT can provide everyone in the network with real-time data on material origin, orders, stocks, shipments and invoices. By linking to a smart contract, the relevant data can be checked against the previously made agreements and payments can be triggered automatically. This allows processes such as sending shipments or confirming deliveries to be automated. At the same time, BCT guarantees a high level of data security due to the decentralized database and the fact that the data cannot be changed afterwards (Cole et al., 2019).

Kim & Shin's (2019) quantitative study also reveals several benefits of the characteristics of BCT for SCM, particularly in relation to SC partnerships and performance. The study demonstrates that characteristics of BCT such as information transparency and immutability as well as smart contracts have a positive effect on partnerships within the SC, which in turn has a positive effect on the financial and operational performance of the SC (Kim & Shin, 2019).

Park & Li (2021) illustrate the advantages of BCT in SCM based on the following four characteristics: traceability, reliability and security, synchronized transaction process and cost efficiency. By tracking the location of products in real-time, BCT simplifies the traceability of products, which in turn increases transparency. The decentralized recording and high security of data along the SC reduces the risk of product counterfeiting and at the same time increases consumer trust. In addition, BCT facilitates contract processes in the SC by automating the execution of smart contracts, thus eliminating unnecessary documentation and facilitating the verification of agreements. At the same time, BCT also improves cost efficiency. Especially through traceability and security functions, inventories can be managed more efficiently and thus costs can be reduced (Park & Li, 2021).

2.4.2. Critics of the Use of Blockchain Technology in Supply Chain Management

According to the literature listed above, BCT has many potential benefits for SCM. At the same time, the literature also contains critical remarks and limitations regarding the general applicability of BCT in SCM.

Esmaeilian et al. (2020) consider scalability, security risks and increased energy consumption as the main limitations. The growing number of transactions within the blockchain network, that must be stored and verified in each node, limits the current scalability (Conoscenti et al., 2016; Esmaeilian et al., 2020). Although the security of BCT is presented as its strength in 2.3.2., the required consensus between the nodes for the execution of a transaction poses a security risk (R. Zhang & Xue, 2019). The reason for this is that, depending on the type of blockchain and the chosen consensus mechanism, a certain threshold value is required to take control of a network. The most well-known is the 51% vulnerability of consensus mechanisms, which are typically used in public blockchains where one group of users controls most nodes. Additionally, the endpoints of the blockchain, where users interact and input data, present specific security risks. It is crucial to ensure that only accurate data from the SC is uploaded to the blockchain (Esmaeilian et al., 2020; Zheng et al., 2017). Moreover, the required replication of the blockchain across all nodes results in significant data requirements. This affects scalability, increases costs for data storage and processing, and consumes substantial energy. Depending on the energy source, this can negatively impact the environment (Kumar et al., 2020). It is essential to pay particular attention to this aspect when examining the extent to which BCT can help SCM to become more environmentally friendly. However, as Table 1 shows, there are significant differences in energy consumption depending on the type of blockchain and the chosen consensus mechanism (Zheng et al., 2017).

Furthermore, the smart contract is often criticized in the literature. Although the smart contract can offer a great opportunity for SCM, as described above. At the same time, it is challenging to foresee all possible scenarios that may arise within the SC and to anticipate and code a corresponding regulation within the contract. If certain scenarios are not or poorly coded, this can lead to problems in execution (Cole et al., 2019; Esmaeilian et al., 2020).

Chapter 3: Methodology

The purpose of this thesis is to investigate the potential of BCT in GSCM. The methodological approach to answering the RQ is explained in the following chapter. First, the research design is presented, followed by the chosen approach for data collection and content analysis.

3.1. Research Design

As Figure 2 illustrates, the first step was an in-depth background study on the topics of SCM, sustainability and digital technologies. During this study, it emerged that there is currently a research gap regarding the potential of BCT in GSCM. The RQ of this thesis was then developed on this basis.

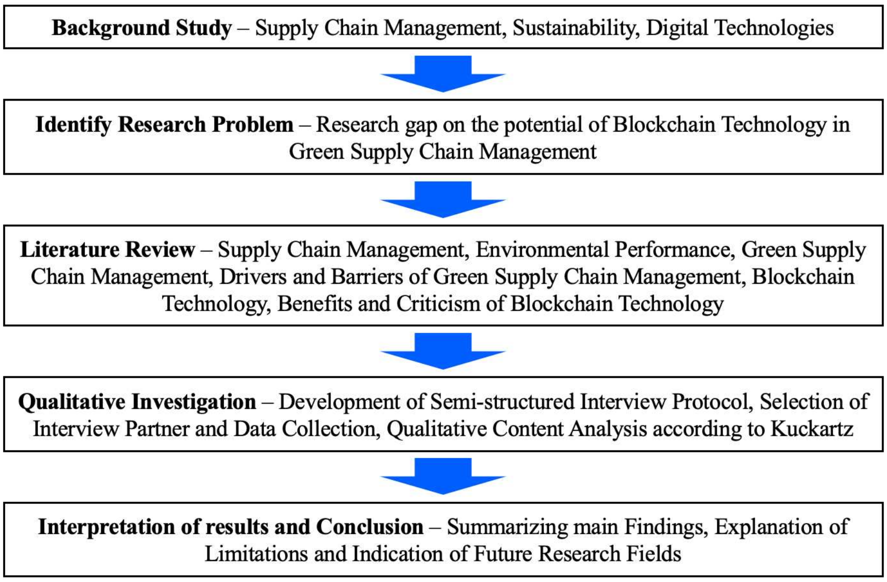

Figure 2: Research Design (Source: Own illustration)

To answer the RQ, a mixture of primary and secondary data was used. The secondary data was obtained by analyzing academic journals and these findings are presented within the literature review presented in chapter two. The detailed literature review serves to critically analyze the current state of knowledge on the RQ and acts as a basis for the collection of primary data (Barriball & While, 1994; Kallio et al., 2016).

To collect the primary data, a qualitative approach with semi-structured expert interviews was then chosen. Qualitative research involves a variety of interpretation techniques and is therefore particularly effective for uncovering phenomena and gaining a deeper understanding of a particular topic (Birkinshaw et al., 2011; Weiss, 1995). Additionally, semi-structured interviews are especially effective for exploring respondents' perceptions and opinions on complex topics, making them particularly suitable for addressing the RQ of this thesis. They also allow spontaneous questions to clarify answers or obtain further information (Barriball & While, 1994; Kallio et al., 2016).

3.2. Primary Data Collection

As explained in section 3.1., the primary data were collected through semi-structured expert interviews. For this purpose, a total of thirteen experts were interviewed (see Table 2). After this number of interviews, a theoretical saturation was reached. The sample size therefore meets the requirements for reliable qualitative research (Guest et al., 2006).

Various criteria were considered when selecting the sample, including expertise, professional experience, organizational roles and educational background of the experts. For the domain expertise, it was ensured that the experts selected have knowledge of either GSCM or BCT, preferably both. In addition, all experts interviewed have at least five years of professional experience, with most having significantly more experience and working in management positions. This is important to gain the perspective of decision-makers on this topic. Given the broad relevance of GSCM in different companies and industries, experts with different backgrounds and from different industries were selected.

The interviews were conducted in the period from 01/04/24 to 24/04/24 using online video calls. They were conducted in German (except for the interview with expert I) the native language of the experts, to ensure clarity and depth of understanding. The duration of the interviews was between 35 minutes and 54 minutes. With prior consent, the audios of all interviews were recorded. The audio files were then transcribed and translated into English for further analysis. The recording of the audio enables an accurate reproduction of the interview, which is particularly important for a detailed and complete analysis (Yin, 2018).

ID	Position	Experience (years)	Expertise	Industry
A	Head of Digital Businesses	>25	GSCM, BCT	Logistic
B	Technical Specialist	>25	GSCM	Technology
C	Chief Operating Officer	>25	BCT	Finance

D	Head of Digitalization & Data Management	5-10	GSCM, BCT	Beverage
E	Project Lead – Trade Finance Innovation Lab	5-10	BCT	Finance
F	Manager (Consultant)	10-15	BCT	Finance
G	Manager (Inhouse Consultant)	5-10	GSCM, BCT	Automotive, Pharmaceutical, Chemical
H	Project Manager	>25	BCT	Energy Technology
I	Lead Digital Supply Chains & Sustainability	10-15	GSCM, BCT	Automotive, Industry Technology & Consumer Goods
J	Procurement Manager	>25	GSCM, BCT	Technology
K	Sustainability Supply Chain Manager	10-15	GSCM	Medical & Safety Technology
L	Co-Founder	5-10	GSCM, BCT	Technology, Food
M	Logistic Process Manager	15-20	GSCM, BCT	Chemical, Metals, Technology

Table 2: Overview of the interviewed experts (Source: Own illustration)

A semi-structured interview guide with open-ended questions was developed in advance (see Appendix 1). The guide contains a total of five blocks, whereby the first block is used to introduce the experts and the last block is used for the option of additional comments from the experts. The questions in the three main blocks cover various key topics that complement each other logically and therefore serve to answer the RQ effectively. Therefore, the second block is about capturing the experts' opinions on the fundamental barriers they see in SCM regarding environmental sustainability and how companies are currently addressing them. The questions in block three serve to examine the potential of BCT in GSCM. Block four then asks about the feasibility of implementing BCT in GSCM, including the necessary prerequisites and hurdles. This structure allows an understanding of the main barriers and drivers from the perspective of the experts in GSCM before looking at the extent to which BCT can be utilized to support this.

To provide a comprehensive answer to the RQ, it is necessary to understand not only the potential of BCT but also how it can be implemented.

3.3. Analysis of Primary Data

Kuckartz's (2018) content-structuring qualitative analysis was chosen to analyze the interviews. This analysis method is particularly effective for exploring an unknown field of research. The method offers the option of performing a mixture of deductive and inductive categorization. This provides the opportunity to test existing theories, such as the "Drivers of GSCM" and “Barriers of GSCM”, with deductive categories, but also to form new categories inductively based on the interview material (Kuckartz, 2018). It is therefore the most suitable method for answering the RQ of this thesis and is also used in similar studies (Feulner et al., 2022; Herzberg et al., 2022; Miklautsch & Woschank, 2022).

As Figure 3 illustrates, after the initial text work, the main categories were created deductively. The deductively created main categories were derived from the RQ to be answered in this thesis and the preceding literature review. The entire material is then coded and compiled according to the developed main categories. Subsequently, further subcategories were formed in each main category based on the interview material. The subcategories were derived inductively, except in the main categories' "drivers" and “barriers”, as a theoretical basis already existed here from which the subcategories were deductively derived. Further sub-subcategories were then created to provide more detail in the analysis. These were in turn derived inductively, except for the sub-subcategories of the main category "drivers". Finally, the entire material was analyzed again using the finalized category system (Kuckartz, 2018).

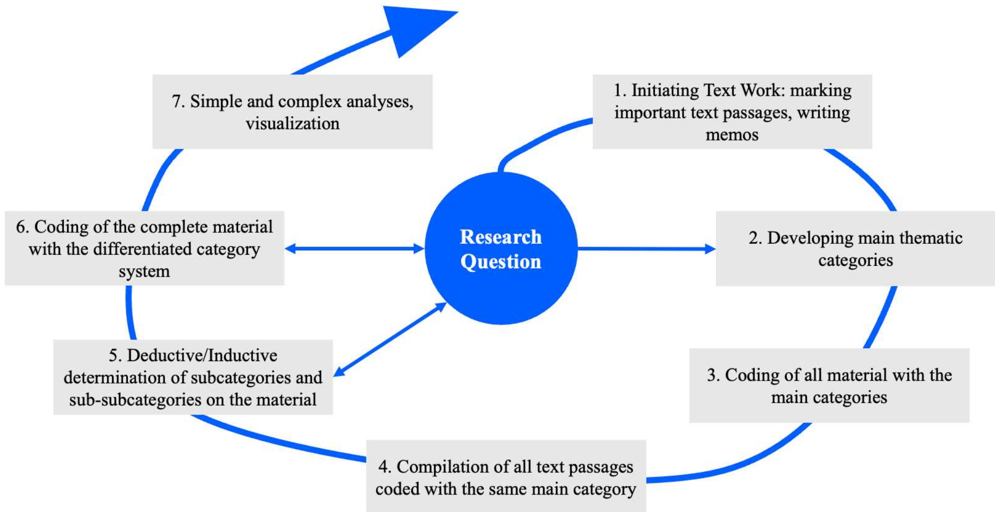

Figure 3: Overview of a content structuring content analysis (Source: Own illustration based on Kuckartz, 2018)

Chapter 4: Findings

The following chapter four systematically presents the results of the expert interviews. As already described in detail in the methodology chapter, the content of the interviews was analyzed based on the content-structuring qualitative analysis according to Kuckartz. A total of six main categories, nineteen subcategories and thirteen sub-subcategories, were developed (see Figure 4), which are presented in the following subchapters of this chapter. Meaningful quotes from the interviews are italicized and marked with an abbreviation and block number. For reasons of clarity, the terms of the categories have been emphasized in bold to make it easier for the reader to understand. All transcripts of the interviews can be found in Appendix 2. Appendix 3 contains the category system developed for the expert interviews, which forms the basis for the presentation of the results. All coded segments of the transcribed interviews according to the developed category system are shown in Appendix 4.

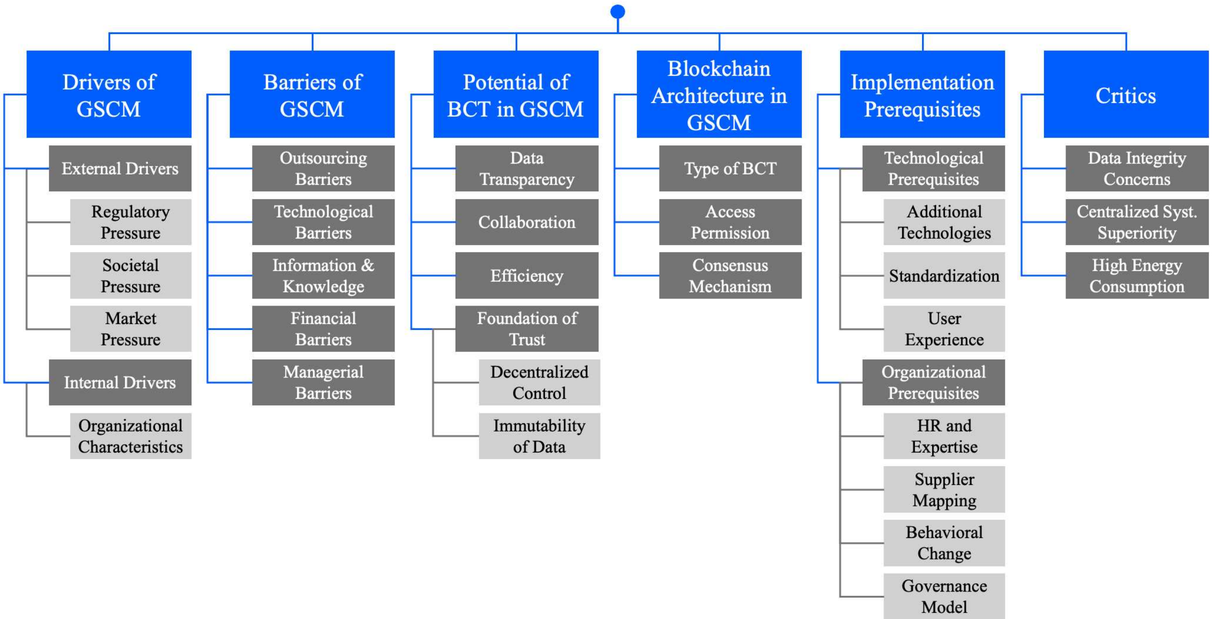

Figure 4: Overview of category system developed with Kuckartz´s methodology (Source: Own Illustration)

4.1. Drivers of Green Supply Chain Management

In the following chapter, the drivers of GSCM named by the experts are analyzed. Based on the framework outlined in chapter 2.2.3, these drivers are categorized into the deductively developed subcategories external and internal drivers with various sub-subcategories.

All experts (except A and I) noted that various **external drivers** can cause companies to take environmental initiatives. All experts stated (except A, B and I), that **regulatory pressure** is a major driver.

“Thanks to political initiatives, there is now also legislative pressure, i.e. the German Supply Chain Due Diligence Act” (Expert C, 6).

Five experts (B, D, E, G, M) noted that **social pressure** also drives companies to implement environmental initiatives. Expert B is of the opinion that non-environmentally friendly products are no longer in demand by end consumers. Expert M commented that although environmental initiatives often mean additional costs at the beginning, if social pressure is great enough due to falling demand, companies will adjust accordingly.

Five experts (E, J, K, L, M) identified **market pressure** as a driver for GSCM. This pressure comes from market expectations and financial considerations. For instance, expert E mentioned that banks take environmental standards into account when granting financing, which has an impact on the interest rates charged. Expert K noted that companies often align their environmental practices with the environmental goals of their main customers.

“Our biggest customers have their own environmental targets, such as being carbon neutral” (Expert K, 14).

The experts rarely mentioned the **internal drivers** of GSCM, with only five experts (C, D, G, L, M) citing **organizational characteristics** as an influencing factor. According to the experts (C, D, G, L), industries vary significantly in their response to external pressures, with some being more proactive than others.

„Some industries are more advanced than others. For example, in the tobacco industry, there are already companies that have implemented traceability all the way to the field” (Expert L, 6).

Additionally, expert M emphasized the role of geographical location, stating that companies in Western countries prioritize GSCM initiatives more highly than those in Latin America, Asia, or Africa.

4.2. Barriers of Green Supply Chain Management

This chapter illustrates the identified barriers by experts for the implementation of a GSCM. Understanding the barriers is important for analyzing the potential of BCT to solve these barriers and answering the RQ. The experts mentioned different barriers. Based on the literature review in chapter 2.2.4, five subcategories of barriers were deductively developed.

Among all barriers, those related to **outsourcing** were mentioned most frequently. All experts (except B) identified issues that fall into this category. Most experts (A, D, F, G, I, K, L) indicated that outsourcing tasks to external parties, such as logisticians or suppliers, leads to a lack of data transparency. Experts F, G, K, and L noted that companies generally lack access to data beyond their direct suppliers, hindering proper EP monitoring and GSCM implementation.

"Many companies only have information on their direct suppliers, whereas today's supply chains consist of numerous steps. (...) This lack of transparency is a significant obstacle, especially when it comes to implementing sustainability initiatives along the supply chain" (Expert L, 4).

Experts A, D, and I highlighted that companies often lack knowledge on how to measure certain processes, such as emissions tracking. Most experts (C, F, G, H, I, J) also identified the lack of data integrity as a significant challenge due to outsourcing. Most companies distrust the accuracy of data provided by their suppliers. Expert G emphasized the high risk of data manipulation, particularly when significant value is associated with the data.

"A fundamental challenge arises from the level of trust placed in data from other parties, particularly when significant value is involved. The greater the value associated with the data, the higher the risk of falsification or manipulation, exacerbating the trust issue" (Expert G, 6).

Experts (C, D, G, I, J, M) pointed out that outsourcing leads to SC fragmentation. Each company uses its own SCM system, often incompatible with others. Additionally, many companies prioritize optimizing their processes over collaboration with other SC participants. Five experts (C, F, G, K, L) also noted that outsourcing increases SC complexity.

In addition, several experts (E, G, H, I, J, K, L) cited the lack of regulatory support as a barrier. Expert H mentioned that regulatory delays hinder the timely implementation of environmental projects due to unclear frameworks. Expert L emphasized the scarcity of comprehensive regulations such as the European Deforestation Regulation, which gives companies precise instructions on how to act in the interests of the environment. Expert K raised concerns about current sustainability reporting directives, noting that companies often rely on assumptions rather than precise data.

Some experts (A, D, F, G) mentioned **technological barriers** to the introduction of GSCM. Experts D and G noted that while technologies like sensors can track environmental parameters, smaller companies often lack the expertise to integrate these tools effectively. Experts A and F highlighted the challenge of analyzing complex and dynamic environmental data.

„However, one challenge is how to deal with the enormous amounts of data in a meaningful way. Collecting data is the most important thing to begin with, but it is equally important to make this data validatable for strategic decisions" (Expert F, 6).

Only a few experts (D, F, K) identified **information and knowledge barriers**. They pointed out the lack of awareness and sensitivity about which initiatives create real environmental value and how to establish these processes within companies. Expert K reported that some companies are also convinced that they are not in charge of taking responsibility for the environment.

"We are pursuing an avoidance strategy by arguing that our supply chain is not that relevant and that we therefore do not need to report all the details" (Expert K, 8).

Regarding **financial barriers**, most experts (except C, H, I, L) highlighted the significant investment costs involved in implementing GSCM. Companies tend to prioritize initiatives with both environmental and economic benefits, such as carbon emission reduction.

"Companies are always efficiency-orientated, so costs and profits must be in proportion to each other. This means that a company only takes environmental factors into account if it is profitable" (Expert E, 4).

Five experts mentioned various **managerial barriers**. Three experts (A, I, K) noted a lack of mindset and involvement from top management in environmental initiatives. Experts H, K and M claimed that small companies particularly lack the resources to address GSCM challenges.

"Small companies often do not have the capacity and resources to meet these challenges" (Expert M, 4).

4.3. Potential of Blockchain Technology in Green Supply Chain Management

This chapter presents the experts' opinions on the potential of BCT in GSCM. All experts named various potentials of BCT that were categorized into four inductively derived subcategories due to a lack of theory in the literature. Additionally, experts were asked to rate the potential of BCT for GSCM on a scale of one to five, with the average rating being four, indicating that they believe BCT "rather applies" to enhancing GSCM. Most experts (A, B, C, E, F, H, I, L) justified this value by stating that BCT has the potential to create added value due to its characteristics while noting that its effectiveness depends on the specific use case and implementation.

"I would give blockchain technology a rating of four. blockchain technology allows data to be tracked in a more democratic way, but the way it is implemented is crucial to consider. (...), if the blockchain technology has been implemented properly, it can definitely help address the problem" (Expert I, 16).

All experts (except H and J) identified improving **data transparency** as a potential use case for BCT in GSCM. According to expert E, transparency and traceability of the SC are essential for environmental sustainability. Expert L emphasized that understanding the origin of products and transport routes is crucial for implementing environmental initiatives, which BCT facilitates.

"For me, traceability is inextricably linked to sustainability, because sustainability cannot be achieved without traceability. For example, if you don't know where the products come from, you can't guarantee that no deforestation has taken place along the supply chain. In our start-up, we use blockchain to demonstrate traceability across several steps of the supply chain" (Expert L, 8).

Four experts (A, D, E, G) noted that BCT offers opportunities for **collaboration**. According to the experts BCT can reduce system breaks in SCM. Furthermore, BCT enables all participants along the SC to work with the same data.

"That is the core of blockchain technology, that you can work together on one and the same data because that is a basic prerequisite for being able to optimize sustainability aspects across companies at all" (Expert A, 10).

BCT has the potential to significantly increase **efficiency** in SC, as most experts (A, B, C, E, G, H, M) indicated. Experts C, E, and G highlighted that BCT can integrate smart contracts into the blockchain, enabling automated initiation of logistical processes and associated payments. Expert E mentioned a case where sensors connected to the blockchain trigger waste collection only when bins are full, reducing carbon emissions by up to 40%.

Most experts (A, C, E, F, G, H, I, J, L), emphasized that BCT provides a **foundation of trust**, particularly in complex and anonymous SCs. Expert L cited an example in the cocoa SCs where

BCT can prevent fraud, such as selling more certified organic cocoa than produced, thereby creating trust between trading partners.

„In anonymous supply chains, there is a significant incentive not to share data truthfully. Here we need an approach that creates a basis of trust, and that is the reason why we opted for a blockchain solution" (Expert L, 8).

According to several experts (C, E, F, H, I, L), a key feature of BCT, that establishes trust, is the **decentralized control** over data. Expert C described BCT as a decentralized network where every participant holds the same data locally. Expert I explained that decentralized control democratizes data, which is essential for trust in SCM. Seven experts (B, C, F, G, I, L, M) noted that this decentralization makes it more difficult to falsify data and therefore increases the **immutability of the data**. Expert B highlighted that once data is stored in the blockchain; it cannot be altered. For instance, Expert L highlighted that a distributor in the cocoa SC cannot resell eight tons of certified cocoa if the blockchain records show that they only received four tons from the farmer.

4.4. Blockchain Architecture in Green Supply Chain Management

This chapter presents the experts' views on the blockchain architecture to be selected, organized into three inductively derived subcategories. All experts (except K) are familiar with the technical implementation of BCT.

Six experts (A, C, I, J, L, M) agreed that a public blockchain, due to its high level of decentralization and data immutability, would be the ideal **type of blockchain**. However, they noted that it is not feasible in SCM because companies prefer to remain anonymous. To preserve competitive advantage, not every participant in the blockchain should have insight into the source of a retailer's goods. Therefore, according to all experts (except K), a consortium blockchain, which is a mixture of private and public blockchain, is the preferred solution.

„In an ideal world, the optimal solution would be a public blockchain, (...). In practice, however, this is often not feasible, as companies often wish to remain anonymous. (...) We opted for a consortium solution, which is a mixture of public and private blockchain“ (Expert L, 16).

Regarding **access permission**, most experts (A, B, C, F, I, L, M) stated that they prefer a permissioned access mechanism, as this is automatically implied by the decision in favor of a consortium blockchain.

"It should be a permissioned-based blockchain, so that it's basically open to everyone, but I can choose who is allowed to use it" (Expert A, 18).

Expert M emphasized that permissioned access does not prevent end consumers from viewing the SC. This access is essential for consumers to make informed decisions about ecologically sustainable products.

"Here must be mechanisms in place to restrict certain data while at the same time an accredited result is visible to the public" (Expert M, 16).

Most experts (A, B, C, E, H, I, L) supported the use of a proof-of-stake **consensus mechanism** since this method is more environmentally sustainable than proof-of-work, which requires significantly higher computing power. Five experts (A, C, H, I, L) noted that with a permissioned consortium blockchain in SCM, it is unnecessary for all participants to agree on every transaction. Instead, a few trusted and distributed nodes can approve transactions.

Finally, five experts (C, H, I, L, M) emphasized that the blockchain architecture to be selected should ultimately always depend on the specific use case.

4.5. Prerequisites for the Implementation of Blockchain Technology

This chapter presents additional insights provided by experts on the prerequisites for implementing BCT in GSCM. These considerations are organized into two inductively derived subcategories with various sub-subcategories.

All experts (except B and H) highlighted several **technical prerequisites** for the successful implementation of BCT in GSCM. Four experts (A, E, I, L) emphasized the necessity of integrating **additional technologies** such as sensors to enhance BCT's effectiveness.

"If the aim is to track the carbon emission of the truck, then a corresponding sensor can be connected directly to the truck's on-board computer, which feeds the corresponding data directly into the blockchain" (Expert A, 18).

Most experts (except A, B, H and I) stated the importance of using **standardized blockchain solutions** as a technical prerequisite for interoperability with existing systems. Expert E noted that there are many different blockchain-based software solutions on the market and that the SC participants need to agree on a standard. Expert L further stated that this selected blockchain standard must be interoperable and seamlessly connected to existing systems.

"Interoperability is crucial in the supply chain industry as no single software solution will prevail. (...) Nevertheless, interoperability remains crucial as it allows us to interact seamlessly with other systems" (Expert L, 18).

Several experts (A, D, F, L) highlighted the importance of the **user experience**. According to expert L, the blockchain's user interface must be intuitive so that SCM personnel can transition smoothly from their previous systems.

All experts (except B and K) identified key **organizational prerequisites** for implementing BCT in GSCM. Six experts (A, D, E, H, I, L) stated that there is a need for **expertise and human resources** familiar with the implementation of BCT. Expert I mentioned that despite BCT not being overly complex, few individuals have the necessary expertise.

"Although blockchain technology itself is not actually a complex technology that only a few are able to program, there is simply a lack of understanding" (Expert I, 22).

Three experts (D, F, L) noted that companies must conduct thorough **supplier mapping** before implementing BCT. Expert L explained that while BCT can enhance trust and transparency, companies must first trace the origin of their products within the SC before implementing blockchain in SCM.

Most experts (except B, E, H and K) stressed that successful BCT implementation depends on the acceptance and involvement of all SC participants, therefore a **behavioral change** is needed, and the right incentives must be created. Expert L emphasized that suppliers must understand the necessity of entering their data into the blockchain to continue selling their goods. Expert J suggested that creating incentives, such as the potential for higher prices for raw materials, could encourage participation.

Most experts (A, B, D, G, I, J, K, M) highlighted the need for a robust **governance model**. Expert I noted that many blockchain networks fail due to the lack of a solid governance framework. Expert K added that this model should define data upload requirements, access permissions, and data storage. Expert J emphasized that the governance model should ensure that all SC participants benefit equally from BCT implementation.

"A reasonable governance model must also be developed as a framework. (...) Many such networks that are initiated by companies do not work because they do not have a good governance model" (Expert I, 20).

4.6. Critics

This chapter addresses criticisms related to the use of BCT in GSCM. Three primary points of criticism emerged from expert interviews, categorized into inductively derived subcategories. Both criticisms and counterarguments from the experts are presented for each subcategory.

One significant concern raised by experts is the **integrity of the data**. Four experts (B, E, I, J) highlighted that there is no guarantee that the data has not already been manipulated when it is entered into the blockchain. Expert L acknowledged the risk of data manipulation but argued that BCT allows for the detection of inconsistencies over time, which can reveal fraudulent entries.

"It is possible to enter incorrect data, but if this happens over a longer period, it will be very difficult not to uncover inconsistencies. Node operators have access to all past data in their databases and can use this past data to assess the credibility of new data. For example, if a coffee roaster claims to have roasted 10 tons of certified coffee but has only received 6 tons, this would attract attention" (Expert L, 22).

Some experts (A, C, J) questioned the added value of BCT compared to other **centralized system solutions**, noting that BCT does not inherently improve the EP of SCM.

"Blockchain is just a way of storing data, namely in a decentralized network instead of a centralized network. And that doesn't make anything more environmentally friendly per se" (Expert C, 8).

Moreover, according to expert C, BCT in itself does not improve the EP of SCM. In contrast, three experts (F, L and M) argued that while a BCT does not directly lead to an improvement in EP, its decentralized nature facilitates the involvement of all partners along the SC, which promotes transparency and trust.

Three experts (E, F, I) expressed concerns about the **increased energy consumption** of BCT. However, six experts (A, C, D, G, H, L) countered this criticism, claiming that the blockchain solutions used in SCM are no more energy-intensive than traditional software, distinguishing them from high-energy-consuming systems like Bitcoin.

"For example, our system consumes less power than the average refrigerator, which makes it particularly attractive from a sustainability perspective" (Expert L, 18).

Chapter 5: Discussion

The primary objective of this thesis is to investigate the potential of BCT in GSCM and how it can be implemented. The findings from the interviews partly confirm the findings of the existing literature on GSCM and BCT. Furthermore, they create the previously non-existent bridge between the two topics and therefore offer further relevant academic insights and managerial implications beyond the existing literature.

5.1. Contributions to Theory and Practice

This thesis provides a variety of new insights that contribute to both theory and practice. To present these insights systematically, they are discussed using the identified main categories from chapter four.

(1) Drivers of GSCM

First, this thesis enriches the existing body of knowledge by analyzing the drivers of GSCM in detail. A deep understanding of these drivers of GSCM is essential to comprehend the potential of BCT and to answer the RQ. The analysis of the results highlights the dominant role of external drivers. This is consistent with the previous findings of the literature review (Saeed & Kersten, 2019).

In addition, the results from interviews reveal the specific role of regulation as an external driver. While previous studies emphasize the general role of regulatory pressure (Hsu et al., 2013), this thesis delves into how recent regulations affect GSCM adoption, contributing to a deeper understanding of how contemporary regulatory frameworks shape companies' environmental strategies. It underlines the divergent views on the influence of new regulations such as the German Supply Chain Due Diligence Act or the Corporate Sustainability Reporting Directive. On the one hand, experts see those regulations as a driving force that encourage companies to take environmental initiatives. On the other hand, some experts see regulations also as a barrier, which is discussed in the following second section of this chapter.

Additionally, the findings show the increasing influence of consumer preferences on the adoption of GSCM. This demonstrates the need for companies to respond to society's expectations and incorporate consumer feedback into their GSCM strategies. By detailing how granting bank loans and customer expectations drive GSCM, the study provides a comprehensive overview of the market dynamics influencing environmental initiatives. This highlights the interconnectedness of SCs and the importance of aligning with broader market expectations to achieve GSCM. These findings provide a nuanced insight into the role of social and market pressures but are broadly consistent with previous findings in the literature (Jahn et al., 2017).

In addition, this thesis reveals the minimal role of internal drivers, suggesting that internal drivers such as organizational culture or resources play a minimal role in promoting GSCM. These finding challenges some of the existing literature that views internal factors as important motivators (Köksal et al., 2017). It suggests that while internal drivers can support and enhance GSCM, they are often secondary to external drivers.

(2) Barriers of GSCM

Second, this thesis provides new insights into the main barriers to GSCM, thereby deepening the understanding of the barriers companies face in adopting GSCM. Understanding these barriers is crucial for identifying the potential of BCT to mitigate these barriers.

In this regard, the results of the expert interviews indicate that the barriers posed by outsourcing practices are the biggest barrier to the adoption of GSCM. This contrasts with the literature, in which outsourcing barriers are only in second place (Govindan et al., 2014). Identifying outsourcing as a primary barrier adds a new dimension to the understanding of GSCM barriers. This finding suggests that future efforts to promote GSCM should focus on improving data transparency and integration in outsourced SCs. Companies need to adopt technologies and practices that facilitate seamless data sharing and increase trust between SC partners to reduce SC fragmentation. In addition, the incomplete regulatory framework is another barrier to outsourcing, reflecting the divergent views of the role of regulation mentioned in the previous section. Indeed, while robust regulations can drive the adoption of GSCM, the lack or unclarity of such a framework can also hinder progress. This is because there is not only a lack of concrete guidelines for companies to implement environmental initiatives but also a lack of funding that is tied to the adoption of concrete regulations when they are unclear. This emphasizes the need to establish clear, enforceable and supportive regulations for policymakers. These regulations must incentivize companies to adopt GSCM without imposing unnecessary burdens on them.

Furthermore, the results reveal that companies prefer environmental initiatives that are financially viable, which is consistent with the financial barriers identified in the literature (Moktadir et al., 2018). Therefore, governments and financial institutions should develop financial mechanisms that support initiatives that are not necessarily financially profitable but are environmentally necessary. Those financial mechanisms can include subsidies and tax breaks for companies that adopt comprehensive GSCM practices.

Finally, the thesis shows that technical, managerial, and informational barriers are less prominent in the minds of experts. Nevertheless, companies should also address those barriers by developing strategic plans for environmental sustainability and expanding their knowledge base on green practices to create a more favorable environment for GSCM.

(3) Potential of BCT in GSCM

Third, the findings in this thesis highlight the significant potential of BCT as an enabler for implementing a GSCM, thereby addressing the first part of the RQ. While previous studies focus on the operational and financial benefits of BCT in traditional SCM (Kim & Shin, 2019), the results from this thesis underline the potential of BCT to improve environmental sustainability. Cole (2019) highlights several characteristics of BCT in his study, such as providing a unified data source through its distributed ledger and promoting transparency, collaboration and efficiency among SC participants. The findings of this thesis confirm these characteristics of BCT identified in the literature also for the GSCM. The analysis of the interviews suggests that BCT can reduce barriers of GSCM and enable its successful implementation both directly and indirectly, as shown in Figure 5.

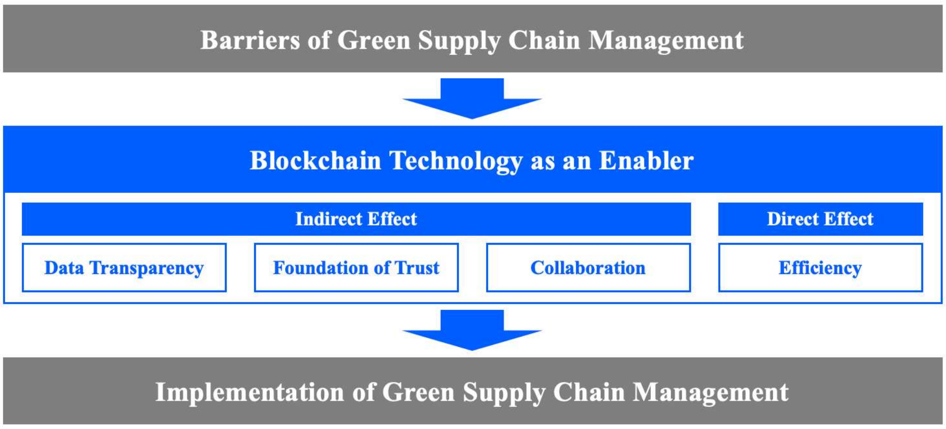

Figure 5: Blockchain technology as an enabler for green supply chain management (Source: Own illustration)

In particular, the results of this thesis show that BCT can reduce barriers related to outsourcing in SCs, such as the lack of data transparency and integrity as well as fragmentation and complexity. This is because BCT's distributed ledger ensures that all SC participants have access to consistent, real-time information. This creates transparency, which in turn enables companies to closely monitor environmental indicators and thus maintain accountability within the SC. The immutability of blockchain records builds trust between SC partners, which is critical for verifying environmental practices and maintaining stakeholder confidence. In addition, all participants can always access the same data at the same time, reducing the current fragmentation of the SC and promoting effective collaboration between SC participants. While these characteristics do not make SCM greener per se, they provide the framework to lower current barriers and can have an indirect effect on the successful implementation of GSCM. Moreover, by rationalizing SC processes, BCT can reduce redundancies and inefficiencies, which leads to lower resource consumption and emissions. This optimization can contribute directly to environmental sustainability and improve overall operational performance.

(4) Blockchain Architecture in GSCM

Fourth, this thesis provides companies with a comprehensive understanding of what a blockchain architecture in GSCM could look like. Although various blockchain types, access permissions and consensus mechanisms are described in the literature (Cole et al., 2019; Zheng et al., 2018), there is little guidance on the optimal blockchain architecture specifically for GSCM. This thesis fills that gap by offering practical insights from industry experts.

Based on the experts' findings, this thesis shows that only a permission-based blockchain is feasible in a corporate context. This limits access to authorized participants. Furthermore, it ensures that only verified companies can contribute to and view the blockchain data. This is essential for maintaining the integrity, confidentiality and security of sensitive SC information. Moreover, the findings show that although a permission-based blockchain is recommended, the architecture within this framework should be as open as possible. Therefore, most experts advocate a consortium-based blockchain solution, where a group of predefined organizations manages the blockchain. This approach balances the need for controlled access with the benefits of increased transparency and collaboration among key SC participants. These architectural recommendations are grounded in practical experience from industry experts and provide a clear blueprint for companies looking to implement BCT in their SCs to enhance EP.

(5) Implementation Prerequisites

Fifth, this thesis provides companies with important insights into the prerequisites for the introduction of BCT in GSCM. While there is hardly anything to be found in the literature regarding these specific prerequisites, this thesis gives clear guidance here, which can be divided into technological and organizational prerequisites. There are two parallels between the organizational prerequisites for the implementation of BCT resulting from the interviews and the barriers in GSCM identified by the literature.

First, the results of this thesis show that specialized knowledge is essential for the implementation of BCT in GSCM. At the same time, the existing literature suggests that a lack of knowledge about green practices is also a significant knowledge and information barrier for GSCM (Govindan et al., 2014).

Second, this thesis demonstrates that a sound governance model is required for successful BCT adoption. This model should define the requirements for uploading data, access authorizations and data storage. At the same time, it must ensure that all SC participants benefit equally from the BCT implementation. This is crucial for the sustainability and effectiveness of the blockchain network. This is in line with the management barriers identified in the GSCM literature, which emphasize the lack of implementation plans for environmental initiatives (Jianguo & Solangi, 2023).

This high similarity between the two organizational prerequisites for the implementation of BCT in GSCM mentioned by the experts and the barriers from the literature in relation to the introduction of GSCM, suggests a holistic approach. Companies should consider and address these topics comprehensively to exploit synergy effects and make optimal use of resources. After all, BCT can only realize its full potential in GSCM if companies succeed in overcoming the barriers and creating the necessary prerequisites for the implementation of BCT.

Furthermore, this thesis provides additional insights into the technical prerequisites that are necessary for the implementation of BCT in GSCM, although fewer parallels to the barriers can be recognized here. These include the need to integrate additional technologies such as sensors to increase the effectiveness of BCT. In addition, the results indicate the importance of standardized blockchain solutions to ensure interoperability with existing systems and enable seamless interaction between different software solutions used by different SC participants. Finally, a user-friendly interface is crucial to facilitate the transition of SC personnel from previous systems to blockchain-based systems. This analysis addresses the last part of the RQ by outlining the prerequisites for the implementation of BCT in the GSCM. The insights gained in this thesis provide a comprehensive framework for companies to prepare for and facilitate the integration of BCT into their SCs.

(6) Critics

Sixth, this thesis addresses common criticisms of the use of BCT in GSCM. In the literature, BCTs are often criticized for their high energy consumption and problems with data integrity.

Here this thesis offers a more nuanced view of the criticism through expert knowledge. Firstly, concerning the high energy consumption of BCTs noted in the literature and its potential negative impact on the ecological footprint (Kumar et al., 2020). Experts point out that modern blockchain solutions used in SCM are increasingly energy-efficient and in line with the objectives of the GSCM. It is therefore possible that BCT can support environmental goals in SCM without the high energy consumption associated with blockchain applications such as Bitcoin.

Another critical point raised in the literature is the potential for data manipulation before it is entered into the blockchain (Esmaeilian et al., 2020; Zheng et al., 2017). While the experts partially share this concern, they also point out that BTC can expose inconsistencies over time, increasing the overall reliability of the data in the long term. In addition, the integration of sensors and other verification mechanisms can minimize the risk of manipulation at the entry point and thus eliminate an important point of criticism. Nevertheless, future research is essential to develop mechanisms that further minimize these risks and increase the attractiveness of using BCT in GSCM. By addressing these criticisms, this thesis provides a comprehensive understanding of both the limitations and potential solutions associated with the implementation of BCT in GSCM.

5.2. Limitations and Future Research

The thesis provides many new insights regarding the role of BCT in GSCM, but there are also some limitations and potential areas for future research. These are outlined in the following subchapter.

Firstly, semi-structured interviews were used to answer the RQ. As the researcher needed a detailed understanding of the topics of GSCM and BCT to conduct the interviews, the chosen research method offers high internal validity. However, semi-structured interviews offer only low external validity. As a result, the insights gained from them often have low generalizability due to the non-probabilistic sampling method, which means that the findings cannot be generalized (Leung, 2015). Here, future research could address the issue by quantifying and verifying the findings through quantitative research, such as surveys.

Secondly, the findings of this thesis are based exclusively on the opinions of the thirteen interviewed experts. Although care was taken when selecting the experts to ensure that they had as broad a background to obtain many perspectives on the topic, there are limitations to be noted here. On the one hand, the number of interviewees was limited due to time and resource constraints. In this respect, interviewing more experts might have provided additional insights. On the other hand, the interviewees had mainly a Western view of the topic and their companies they work for tend to be at the end of the SC. Here future research could focus on the perspective of suppliers at the beginning of the SC, such as raw material producers. As the findings show, it is essential for the success of the BCT to involve the participants of the entire SC.

Thirdly, BCT is a technology that is constantly evolving and its use in SCM is still at the beginning. This thesis therefore only provides insights into the current (April 2024) state of knowledge. However, it can be assumed that BCT will evolve over time and that its use in SCM will also change as a result. In addition, the development of the regulatory framework in the coming years will play an essential role in the extent to which companies take environmental initiatives and possibly use BCT as support. Therefore, the findings of the thesis could become less relevant over time and provide the need for future research.

Chapter 6: Conclusion

The progressive climate change demonstrates the necessity for companies to implement environmentally sustainable practices in SCM. One approach to this end is the introduction of a GSCM. A review of the literature reveals that while the introduction of GSCM is driven by various factors, it also faces significant barriers. In this context, digital technologies, particularly BCT, are suggested as possible solutions for dealing with the barriers. However, despite its promising potential in this context, BCT is quite unexplored by the literature. This thesis addresses this gap by investigating the potential of BCT in GSCM and exploring possible implementation strategies.

The results of this thesis are based on the analysis of thirteen semi-structured expert interviews. These were analyzed with the help of Kuckartz's content-structuring qualitative analysis method, which provided valuable insights into the drivers and barriers to the implementation of GSCM. One major barrier identified is the outsourcing of activities along the SC, which has led to fragmentation, lack of transparency regarding suppliers, and insufficient regulation in many industries. The findings indicate that regulation can act as both a driver and a barrier, emphasizing the necessity for a more comprehensive regulatory framework to support the success of GSCM.

The investigation into BCT's potential reveals its capacity to mitigate these barriers by enhancing trust, fostering collaborative cooperation among SC participants, and increasing data transparency. BCT thus enables more effective implementation and monitoring of environmental initiatives across the SC. Moreover, BCT can enhance the efficiency of the SC, which has a direct positive impact on the environment. This demonstrates the potential of BCT in GSCM and addresses the initial research question. Regarding the implementation of BCT in GSCM, this thesis provides practical guidance for companies to design the blockchain architecture. The results suggest that companies should opt for a permission-based consortium blockchain. In addition, this thesis outlines various technological and organizational requirements necessary for the successful integration of BCT into GSCM. It also addresses common criticisms of BCT, such as high energy consumption and the risk of data manipulation and shows that these issues are no longer a major obstacle to implementation.

This thesis makes an important contribution to both theory and practice in two ways. Firstly, it demonstrates the significant potential of BCT to overcome barriers associated with GSCM. Secondly, it provides a roadmap for the practical implementation of BCT. Companies that adopt

BCT can improve their EP and gain a competitive advantage in the sustainability-driven marketplace.

Chapter 7: References

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Appendix 1: Interview Guide

Block 1: Introduction and general background information

Can you please briefly introduce yourself (your professional experience in years and expertise in supply chain management and/or blockchain technology)?

Block 2: Challenges in environmentally sustainable supply chain management

1. From your perspective, what are the biggest challenges regarding environmental sustainability in supply chain management?
2. What do you think is the current approach of companies to deal with these challenges in supply chain management?
3. To what extent and in which areas of supply chain management does the use of digital technologies already play a role in dealing with these challenges?

Block 3: Potential of blockchain technology to improve environmental performance in supply chain management.

1. To what extent can blockchain technologies theoretically help with the challenges mentioned and why?
2. Which characteristics of blockchain technology play a crucial role in potentially overcoming the challenges?
3. Do you believe that blockchain technology is a potential key technology for improving environmental performance in supply chain management?
4. On a scale of 1 to 5 (with 1 being the lowest and 5 the highest), what potential do you see for blockchain technology to improve the environmental performance of supply chain management?

Block 4: Implementation of blockchain technology in (green) supply chain management

1. How can blockchain technology be implemented in green supply chain management?
2. What requirements must be met for the successful implementation of blockchain technology in green supply chain management?
3. What barriers and risks do you see for the implementation of blockchain technology in green supply chain management?

Block 5: Outro

Do you have any other comments on the topic of how blockchain technology can improve environmental performance in supply chain management?

Appendix 2: Transcripts of Expert Interviews

Due to the limited number of pages in the Appendix, the transcripts of the thirteen expert interviews can be found in a Dropbox and viewed via the respective links. If the link does not work, please contact the author of this thesis at the following email address: s-llorenzen@ucp.pt

Expert A

https://www.dropbox.com/scl/fi/i095d53gr94bhoor792c9/Expert_A_Interview.pdf?rlkey=vczoywp3buc46ogcj2y1y63x2&st=g8yoky5l&dl=0

Expert B

https://www.dropbox.com/scl/fi/jse6ydiyfwpoap9ar97ey/Expert_B_Interview.pdf?rlkey=dy56r0x4xzkbrkzerp5w47n8u&st=0yiujyyk&dl=0

Expert C

https://www.dropbox.com/scl/fi/9ew8zkbwk5e21r2gb7knc/Expert_C_Interview.pdf?rlkey=f8bisvt9no3aj9ripvj3xizhw&st=0q7mbmwr&dl=0

Expert D

https://www.dropbox.com/scl/fi/94lqyzzjbqdxc7dyq6i2a/Expert_D_Interview.pdf?rlkey=y71a75z1j3h2orldm1l4ev1t1&st=iqbh02nn&dl=0

Expert E

https://www.dropbox.com/scl/fi/ta2akxcodv5wmo0nxh7gx/Expert_E_Interview.pdf?rlkey=02yx92uda4mp5j8ro4yy465af&st=1ta77pqj&dl=0

Expert F

https://www.dropbox.com/scl/fi/mxvi638mw2fgwztdfu7ni/Expert_F_Interview.pdf?rlkey=1kwplh5vfpm9g77gz4xvpjj54&st=fzf2zs80&dl=0

Expert G

https://www.dropbox.com/scl/fi/vqmifojp0ph13gmqvkhvo/Expert_G_Interview.pdf?rlkey=xfvozvhl97clg59oif8zhgnkx&st=h8usdmqa&dl=0

Expert H

https://www.dropbox.com/scl/fi/yw9xfy6x4ouzqh7tp2za4/Expert_H_Interview.pdf?rlkey=u5k8o81xk6knj19e9cdgv2vxm&st=t20bw99z&dl=0

Expert I

https://www.dropbox.com/scl/fi/theoke9ouw2qaqoz0kloo/Expert_I_Interview.pdf?rlkey=bds5epncqjx2k81umibgt9yla&st=9asj3guc&dl=0

Expert J

https://www.dropbox.com/scl/fi/shtrelwbf8qefsf979jo6/Expert_J_Interview.pdf?rlkey=nbu9deukc7uax11r4cfxuqttf&st=n855bknk&dl=0

Expert K

https://www.dropbox.com/scl/fi/407n1o8c9tg8bis886704/Expert_K_Interview.pdf?rlkey=h735asb583ovk38phzsukwdha&st=8j2lp1dj&dl=0

Expert L

https://www.dropbox.com/scl/fi/172ehd6vtcek0ca3stzcy/Expert_L_Interview.pdf?rlkey=dz09vrfieff0kz537hpm1d798&st=9izcp2xt&dl=0

Expert M

https://www.dropbox.com/scl/fi/x1va1wag9xd3l18m8q22x/Expert_M_Interview.pdf?rlkey=i7m8vrpjqgnv02as8c022ken4&st=t1wdxmqz&dl=0

Appendix 3: Category System

Appendix 3.1.: Main Category 1 – Drivers of GSCM

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	DC	External drivers	Factors that originate outside the company and have an impact on internal environmental initiatives	-	(B, C, D, E, F, G, H, J, K, L ,M)
Sub-Subcategory	DC	Regulatory pressure	Aspects about official mechanisms of regulatory institutions, such as standards, laws, procedures and incentives	Thanks to political initiatives, there is now also legislative pressure, i.e. the Supply Chain Due Diligence Act. (Expert C, 6)	(C, D, E, F, G, H, J, K, L, M)
Sub-Subcategory	DC	Societal pressure	Aspects about social norms and values, that are demanded and expected by interest groups	This means that a company only takes environmental factors into account (…) because it is under pressure from other influencing factors, e.g. society. (Expert E, 4)	(B, D, E, G, J, M)
Sub-Subcategory	DC	Market pressure	Aspects describing the market landscape that forms the context in which the company operates	Our biggest customers have their own environmental targets, such as being carbon neutral. (Expert K, 14)	(E, K, L, M)
Subcategory	DC	Internal drivers	Factors that originate from inside the company and have an influence on the internal environmental initiatives	-	(C, D, G, L, M)
Sub-Subcategory	DC	Organizational drivers	Statements related to companies characteristics that influence the environmental transformation of a company	Some industries are more advanced than others. For example, in the tobacco industry, there are already companies that have implemented traceability all the way to the field. (Expert L, 6)	(C, D, G, L, M)

***DC = Deductive; IC = Inductive**

Appendix 3.2.: Main Category 2 – Barriers of GSCM

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	DC	Outsourcing barriers	Aspects relating to difficulties that arise when outsourcing SC tasks to external parties while ensuring environmental sustainability	Many companies only have information on their direct suppliers, whereas today's supply chains consist of numerous steps. (…) This lack of transparency is a significant obstacle, especially when it comes to implementing sustainability initiatives along the supply chain. (Expert L, 4)	(A, C, D, E, F, G, H, I, J, K, L ,M)
Subcategory	DC	Technological barriers	Statements on challenges in implementing a GSCM due to lack of technology or lack of expertise in using the technology	However, one challenge is how to deal with the enormous amounts of data in a meaningful way. Collecting data is the most important thing to begin with, but it is equally important to make this data validatable for strategic decisions. (Expert F, 6)	(A, C, D, F, G)
Subcategory	DC	Information and knowledge barriers	Aspects relating to knowledge gaps and lack of awareness that represent an obstacle to the introduction of a GSCM	We are pursuing an avoidance strategy by arguing that our supply chain is not that relevant and that we therefore do not need to report all the details. (Expert K, 8)	(D, F, K)
Subcategory	DC	Financial barriers	Statements on financial barriers that pose a challenge when introducing a GSCM.	Companies are always efficiency-orientated, so costs and profits must be in proportion to each other. This means that a company only takes environmental factors into account if it is profitable. (Expert E, 4).	(A, B, D, E, F, G, J, K, M)
Subcategory	DC	Managerial barriers	Statements on managerial barriers that pose a challenge when introducing a GSCM	Small companies often do not have the capacity and resources to meet these challenges. (Expert M, 4	(A, H, I, K, M)

***DC = Deductive; IC = Inductive**

Appendix 3.3.: Main Category 3 – Potential of BCT in GSCM

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	IC	Data transparency	Statements about the potential of BCT to improve the data transparency within GSCM	Blockchain can therefore be seen as the enabler that creates the transparency needed to become more environmentally friendly. (Expert A, 10)	(A, B, C, D, E, F, G, I, K, L ,M)
Subcategory	IC	Collaboration	Statements on the potential of BCT to enable collaboration between participants within the GSCM	That is the core of blockchain technology, that you can work together on one and the same data, because that is a basic prerequisite for being able to optimize sustainability aspects across companies at all. (Expert A, 10)	(A, D, E, G)
Subcategory	IC	Efficiency	Statements on the potential of BCT to increase the efficiency within the GSCM	(...) The tokenization of smart contracts, i.e. automatic processes can be triggered by certain events, can massively increase efficiency. This means an increase in the speed of logistics chains, less waste, i.e. food that has to be thrown away, or less waste of technical things because the quality is not right. (Expert C, 8)	(A, B, C, E, G, H, M)
Subcategory	IC	Foundation of trust	Statements on the potential of BCT to create a foundation of trust in the shared data within GSCM	In anonymous supply chains, there is a significant incentive not to share data truthfully. Here we need an approach that creates a basis of trust, and that is the reason why we opted for a blockchain solution. (Expert L, 8)	(A, C, E, F, G, H, I, J, L)

***DC = Deductive; IC = Inductive**

Sub-Subcategory	IC	Decentralized control	Statements about BCT as a decentralized system that improves EP in SCM	The only reason why we use a technology like blockchain is that it leads to or promotes a democratization of data. This means that all the data in a supply chain does not have to be held and controlled by a single party in the supply chain.(Expert I, 14)	(C, E, F, H, I, L)
Sub-Subcategory	IC	Immutability of data	Statements on the potential of BCT to enable immutable data within the GSCM	The tamper-proof nature of blockchain offers additional security here if there is insufficient trust. (Expert F, 8)	(B, C, F, G, I, L, M)

***DC = Deductive; IC = Inductive**

Appendix 3.4.: Main Category 4 – Blockchain Architecture in GSCM

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	IC	Type of blockchain technology	Statements on the type of BCT that should be chosen in GSCM	In an ideal world, the optimal solution would be a public blockchain, (..). In practice, however, this is often not feasible, as companies often wish to remain anonymous. (...) In our case, we opted for a consortium solution, which is a mixture of public and private blockchain. (Expert L,16)	(A, B, C, D, E, F, G, H, I, L ,M)
Subcategory	IC	Access permission	Statements about the access permission to the blockchain that should be in GSCM	It should be a permissioned-based blockchain, so that it's basically open to everyone, but I can choose who is allowed to use it. (Expert A, 18)	(A, B, C, F, I, L, M)
Subcategory	IC	Consensus mechanisms	Statements on the blockchain consensus mechanisms that should be chosen in GSCM	So clearly not a proof-of-work but rather a proof-of-stake, so that the energy aspect is not critical, otherwise acceptance of this new technology would never be achieved. (Expert C, 16)	(A, B, C, E, H, I, L)
Subcategory	IC	Use case dependent	Aspects that indicate that the choice of the right BCT in GSCM depends on the use case	Basically, there is no one right implementation. Instead, you have to look from case to case. (Expert I, 18)	(C, H, I, L, M)

***DC = Deductive; IC = Inductive**

Appendix 3.5.: Main Category 5 – Implementation Prerequisites

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	IC	Technological prerequisites	Considerations for the technological implementation of BCT in GSCM	-	(A, C, D, E, F, G, I, J, K, L, M)
Sub-Subcategory	IC	Additional technologies	Statements on the use of additional technologies for the implementation of BCT in GSCM	If the aim is to track the carbon emission of the truck, then a corresponding sensor can be connected directly to the truck's on-board computer, which feeds the corresponding data directly into the blockchain (Expert A, 18)	(A, E, I, L)
Sub-Subcategory	IC	Standardization	Consideration of the need for standardization and interoperability to ensure the implementation of BCT in GSCM	Interoperability is crucial in the supply chain industry as no single software solution will prevail. (...) Nevertheless, interoperability remains crucial as it allows us to interact seamlessly with other systems. (Expert L, 18)	(C, D, E, F, G, J, K, L, M)
Sub-Subcategory	IC	User experience	Statements on the user-friendliness required for the introduction of BCT in GSCM	A user interface must be created that allows users in the purchasing area not to notice the difference (Expert L, 30)	(A, D, F, L)

***DC = Deductive; IC = Inductive**

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	IC	Organizational prerequisites	Considerations for organizational readiness for the introduction of BCT in GSCM	-	(A, B, C, D; E, F, G, H, I, J, K, L, M)
Sub-Subcategory	IC	Human resources and expertise	Statements on the need for human resources and expertise for the introduction of BCT in GSCM	Although blockchain technology itself is not actually a complex technology that only a few are able to program, there is simply a lack of understanding. (Expert I, 22)	(A, D, E, H, I, L)
Sub-Subcategory	IC	Supplier mapping	Considerations on the necessity of supplier mapping for the introduction of BCT in GSCM	Before you use blockchain, you need to find a systematic way to go through the supply chain and create a supplier mapping. (Expert L, 24)	(D, F, L)
Sub-Subcategory	IC	Behavioral change	Statements indicating the necessity of a behavioral change and incentivization for a successful implementation of BCT in GSCM	By making it as easy as possible for suppliers to participate. This means keeping the administrative burden and associated hurdles to a minimum, while creating incentives to make participation attractive and therefore more profitable. It is crucial to create the right incentives to encourage participation. (Expert J, 20	(A, C, D, F, G, I, J, L, M)
Sub-Subcategory	IC	Governance model	Consideration of the need for a governance model when implementing BCT in GSCM	A reasonable governance model must also be developed as a framework. (…) many such networks that are initiated by companies do not work because they do not have a good governance model. (Expert I, 20)	(A, B, D, G, I, J, K, M)

***DC = Deductive; IC = Inductive**

Appendix 3.6.: Main Category 6 – Critics

Type of category	DC/ IC*	Description of category	Definition	Anchor example	Number of entries by experts
Subcategory	IC	Data integrity concerns	Statements that indicate concerns about the integrity of data in blockchain systems and emphasize the lack of a guarantee against data tampering	But at the end of the day, if you put garbage in, you get garbage out of the blockchain. This means that the way in which data is collected before it is written to the blockchain is essential to ensure the accuracy of the data, because otherwise you have incorrect data in the blockchain that is stored there forever and cannot be changed. (Expert I, 22)	(B, E, H, I, J, L)
Subcategory	IC	Centralized system superiority	Statements reflecting the perspective that the implementation of BCT offers no advantages over a centralized system in GSCM	The question arises as to whether other centralized systems can be used that are significantly more cost-effective.(Expert J, 16)	(A, C, F, J, L, M)
Subcategory	IC	High energy consumption	Statements criticizing the high energy consumption of BCT and questioning its sustainability and environmental impact compared to other systems	With the classic or original blockchains, which were based on a proof-of-work concept, we have the opposite of sustainability.(Expert E, 16)	(A, C, D, E, F, G, H, I, L)

***DC = Deductive; IC = Inductive**

Appendix 4: Coded Segments by Category

Appendix 4.1.: Main Category 1

Main Category: Drivers of GSCM – Sub-Subcategory: Regulatory pressure		
Text passage	**Expert**	**Block Number**
Thanks to political initiatives, there is now also legislative pressure, i.e. the Supply Chain Due Diligence Act.	C	6
Because when the CSRD directive comes into force, this is definitely something that will need to be verified with data.	D	4
The other topic is CSRD, which will start in 2026, where we have to provide real-time data on our CO2 emissions.	D	10
Due to laws such as the Supply Chain Due Diligence Act or CSRD, the need for transparency will of course become ever greater.	D	20
This means that a company prices in environmental factors when it is required to do so by regulation.	E	4
We must comply with certain regulations, such as sustainability reporting, which is mandatory for every company.	F	4
In addition, all the regulatory issues play an important role, i.e. compliance with EU directives in terms of working conditions, but also fuel emissions.	G	4
If sustainability becomes increasingly important in society, for example due to regulatory requirements such as the Supply Chain Sustainability Act, then there is a need.	G	16
We have the Renewable Energy Directive in Europe and the Inflation Reduction Act in the USA.	H	4
Since the company now wants to export the hydrogen to Europe, it must comply with the CBAM Directive, i.e. it must prove the carbon footprint of this hydrogen. If a hydrogen producer were not to comply with this directive, the customer in Europe would have to pay corresponding punitive tariffs. This means that to comply with the directive, green hydrogen producers need certification of their carbon footprint.	H	8
To comply with legal requirements, contracts are only concluded with suppliers who meet all the necessary requirements.	J	6
In my opinion, the most pressing issue is CSRD, for which we need to produce a convincing sustainability report.	K	8
Regulation is definitely the driver here, without it this would not have happened.	L	28
In addition, of course, there are the corresponding legal regulations.	M	4

Main Category: Drivers of GSCM – Sub-Subcategory: Societal pressure		
Text passage	**Expert**	**Block Number**
If a product is not sustainable, then it is no longer of interest to the customer.	B	4

Because there is practically no worse advertisement for a brand than finding out that your product is contaminated with pesticides, for example.	D	10
This means that a company takes environmental factors into account because it is under pressure from other influencing factors, e.g. society.	E	4
There is a certain hierarchy in the supply chain, in that the supplier must fulfill the requirements of their respective customer. In other words, the customer determines what they want to see in terms of requirements and then discusses with the supplier how this can be fulfilled.	G	6
Companies must not only earn money, but also survive economically in the long term, which means that they must meet the demands of society (..) with regard to the environment, even if this initially incurs additional costs.	M	6

Main Category: Drivers of GSCM – Sub-Subcategory: Market pressure		
Text passage	**Expert**	**Block Number**
However, if you want to offer products that are ESG-compliant or sustainable, then you can do this from a banking perspective by promoting corresponding projects through appropriate conditions for financing. In other words, the financing is tied to corresponding supplier criteria or whether the financing is provided in a corresponding sector. These are levers that a bank has to promote corresponding projects. (…) Suppliers are also expected to be CO2 neutral by 2030, which is actually a requirement here. This means that when selecting suppliers, it will simply be a decisive criterion that they can prove that they are CO2 neutral.	E	6
So there are already great efforts to meet all legal requirements, as there is a risk of no longer being awarded public contracts.	J	6
After all, the competition is not sleeping and customers are also asking more and more detailed questions about environmental friendliness. For example, our biggest customers have their own environmental targets, such as CO2 neutrality. However, our targets are not as ambitious as theirs. The question then naturally arises as to how long we can continue to supply these customers if we neither have the corresponding data transparency nor are we currently aiming to make any major improvements in this direction.	K	14
So even before regulation, some companies were trying to differentiate themselves from their competitors, possibly to push through higher prices and increase consumer loyalty. However, this was clearly a niche area. You could argue that if just a few companies start doing this, the whole market will change. But I see that as realistic in the long term at best.	L	28

It can be said that companies want to become more environmentally friendly (..) because they want to offer their customers added value to remain competitive in the long term.	M	4

Main Category: Drivers of GSCM – Sub-Subcategory: Organizational characteristics		
Text passage	**Expert**	**Block Number**
But even without legal pressure, it has always been in the interest of companies to ensure the traceability of information. Especially in industries where many safety-relevant parts are used that have to meet certain standards. Here it has always been necessary to ensure that you have a trustworthy supplier.	C	6
Because we are part of the food industry, we have to comply with the so-called batch obligation. This means we have to be able to trace exactly which product on which pallet from which batch we have issued to which customer. We have to do this so that if a recall is necessary, we can always trace the batches from source to destination with the necessary metadata.	D	8
Then, particularly in the pharmaceutical sector, it is important that the products you manufacture are exposed to certain conditions during transportation, such as certain temperatures. And as a manufacturer, you have to prove that you meet the relevant conditions. The same applies to suppliers to pharmaceutical companies.	G	4
However, some industries are more advanced than others. For example, in the tobacco industry, there are already companies that have implemented traceability all the way to the field. To achieve this goal, they have tried to drastically simplify their supply chains. This is certainly a promising approach, but it is not suitable for every industry. In the defense industry, such as Airbus fighter jets, systems are already in use that allow traceability across multiple supply chain steps. This is essential due to the level of security required in this industry. However, this is not necessarily transferable to other industries.	L	6
Another contradiction lies in the different perception of the role of sustainability between Western countries and the rest of the world. In regions such as Latin America, Asia and Africa, companies need to optimize their value creation, often at the expense of sustainability, to improve their standard of living.	M	4

Appendix 4.2.: Main Categories 2-6

Due to the limited number of pages in the Appendix, the coded segments by the main categories 2-6 can be found in a Dropbox and viewed via the respective links. If the link does not work, please contact the author of this thesis at the following email address: s-llorenzen@ucp.pt

Main Category 2 – Barriers of GSCM:
https://www.dropbox.com/scl/fi/eicp31elsenqexb5deykn/Main-Category-2.pdf?rlkey=1tof93h5cbir9ldfyu70ya7m4&st=mo56hnh8&dl=0

Main Category 3 – Potential of BCT in GSCM:
https://www.dropbox.com/scl/fi/cor7g2d0i7fpcw2apla0k/Main-Category-3.pdf?rlkey=6rjgmmlrtyr5448jbl30fvm8z&st=4cyy8l8p&dl=0

Main Category 4 – Blockchain Architecture in GSCM:
https://www.dropbox.com/scl/fi/10qgy3i5cgzfx0596qkuh/Main-Category-4.pdf?rlkey=hhjkoze5kkkhii2k70jgdcz9g&st=jomznp31&dl=0

Main Category 5 – Implementation Prerequisites:
https://www.dropbox.com/scl/fi/h8n1t7iczq0w3unvq5mjh/Main-Category-5.pdf?rlkey=c1dz3edxrsyegtaln5neiieh5&st=7p67t5hw&dl=0

Main Category 6 – Critics:
https://www.dropbox.com/scl/fi/puw7xodtjc4o8tnlqh335/Main-Category-6.pdf?rlkey=3n0eqpwej7927s15bbqzdnw60&st=6cl0v3r3&dl=0